Introduction: Intersection Safety Issue Briefs

Enclosed is a series of *Issue Briefs* on various intersection safety-related topics. This is the Second Edition of these briefs. The issue briefs are targeted primarily for traffic engineers and transportation and safety professionals. Many products have developed over the past two years that will help practitioners evaluate causes of intersection crashes and potential solutions. The issue briefs provide practitioners with a substantial number of references and resources for subsequent review and consideration. The materials could also be used by a far wider audience of people and organizations who want to promote intersection safety issues within their area of influence.

The topics that are included within this intersection safety communications kit include:

The issue briefs are available in print form or electronically on the Federal Highway Administration Web site at www.fhwa.dot.gov and on the Institute of Transportation Engineer's Web site at www.ite.org. Issue briefs are available for organizations to use and post on their Web sites. The goal is to provide this information to the widest audience possible within the education, law enforcement and engineering communities and to the general public.

The format of the issue briefs has changed with the second edition. They are now three-hole punched and can easily be placed in a notebook for quick access and for reproduction as required.

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Richard A. Cunard, P.E.
Transportation Research Board

Gregory W. Davis
Federal Highway Administration

Philip Demosthenes
PMX Inc.

John Fegan
Federal Highway Administration

Margaret Gibbs, P.Eng., PTOE
Hamilton Associates

Geoffrey Ho, M.Eng., P.Eng
G. Ho Engineering Consultants

Robert P. Jurasin, P.E.
Wilbur Smith Associates

William C. Kloos, P.E.
City of Portland

Stein Lundebye, P.E.
The World Bank

Hugh W. McGee, Sr., P.E.
BMI-SG Inc.

John McGill, P. Eng., PTOE
Synectics Transportation Consultants Inc.

Barbara McMillen
Federal Highway Administration

Richard B. Nassi, P.E.
City of Tucson

Mike Niederhauser
Maryland State Highway Administration

Stanley F. Polanis
City of Winston-Salem, North Carolina

Tamara Redmon
Federal Highway Administration

Matthew Ridgway, AICP
Fehr & Peers Associates Inc.

Michael Robinson
Federal Highway Administration

Ida van Schalkwyk
University of Arizona

William J. Scully, P.E.
MS Transportation Systems

Edward R. Stollof, AICP
Institute of Transportation Engineers

W. Scott Wainwright, P.E., PTOE
Federal Highway Administration

Brian Walsh
Washington State Department of Transportation

Sany R. Zein, M.Eng., P.Eng.
Hamilton Associates

Should your office require print copies of the Intersection Safety Issue Briefs, please contact:

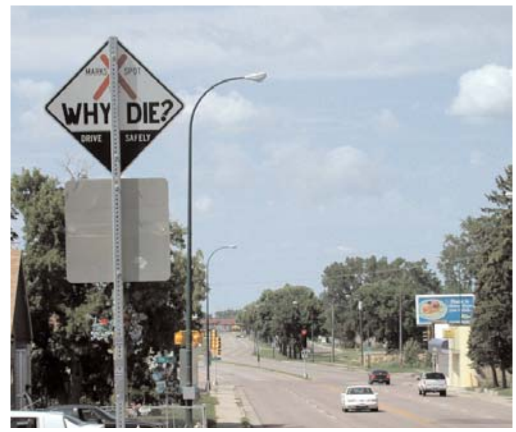
Edward Stollof
Institute of Transportation Engineers
1099 14th Street, NW
Suite 300 West
Washington, DC 20005
Tel: 202-289-0222 x132
Fax: 202-289-7722
E-mail: estollof@ite.org
Web site: http://www.ite.org

or

Hari Kalla, P.E.
Federal Highway Administration
400 Seventh Street, SW
Suite 300 West
Washington, DC 20005
Tel: 202-366-5915
Fax: 202-366-2249
E-mail: hari.kalla@fhwa.dot.gov
Web site: http://www.fhwa.dot.gov

The National Intersection Safety Problem

Identifying the Problem



In 2002 approximately 3.2 million intersection-related crashes occurred, representing 50 percent of all reported crashes. 9,612 fatalities (22 percent of total fatalities) occurred at or within an intersection environment (See Table 1). The cost to society for intersection crashes is approximately $96 billion a year. The number of fatal motor vehicle crashes at traffic signals is rising faster than any other type of fatal crash nationwide.

An intersection is, at its core, a planned point of conflict in the roadway system. With different crossing and entering movements by both drivers and pedestrians, an intersection is one of the most complex traffic situations that motorists encounter. Add the element of speeding motorists who disregard traffic controls and the dangers are compounded.

Despite improved intersection design and more sophisticated applications of traffic engineering measures, the annual toll of human loss due to motor vehicle crashes has not substantially changed in more than 25 years.

Intersection safety is a national, state and local priority. Intersections represent a disproportionate share of the safety problem. As a result, organizations such as the Federal Highway Administration, the Institute of Transportation Engineers and AASHTO, AAA and other private and public organizations are devoting resources to help reduce the problem.

Table 1: Key 2002 National Highway and Traffic Administration (NHTSA) Statistics

	Number	Percentage	Societal Cost in Billion $
Total fatality crashes	38,409		
Total intersection-related fatality crashes	8,760	22.8	22
Total injury crashes	1,929,000		
Total intersection-related injury crashes	1,066,000	55.3	69
Total property-damage-only (PDO) crashes	4,348,000		
Total PDO intersection-related crashes	2,092,000	48.1	5
All crashes	6,316,000		96
Total intersection-related crashes	3,170,000	50.2	
Total fatalities	42,815		
Fatalities at intersections	9,612	22.4	

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Figure 1 shows the 2002 percentage of fatal intersection crashes, by type of traffic control present at the intersection. As shown, there is a balanced distribution of fatal crashes occurring at a traffic signal and a stop sign (approximately one in three crashes each occur at a signal and stop sign.) It is noteworthy that almost one in three crashes occur in locations that have no traffic controls present. A street "with no traffic control" is one where there is no control signal or stop sign for traffic on the street being crossed.

Figure 2 shows the distribution of the 8,760 fatal intersection crashes by manner of collision. As shown, the side impact crashes are the most predominate crash type. Side impact crashes account for over 60 percent of the fatal intersection collisions. Rear-end and head-on crash types each account for five percent of fatal intersection crashes. Almost one in three fatal crashes at intersections do not involve a collision with another motor vehicle that is in motion.

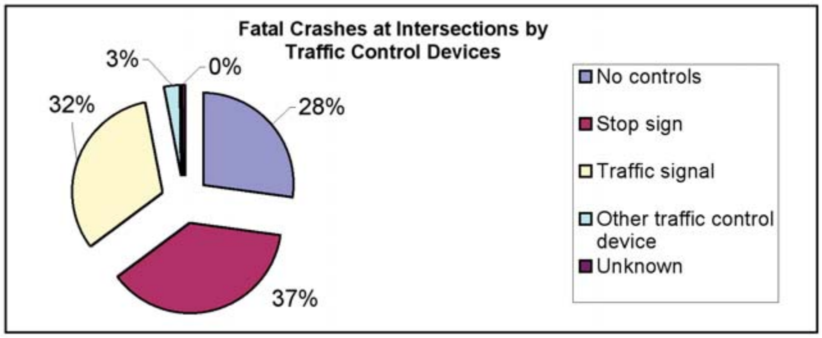

Figure 1

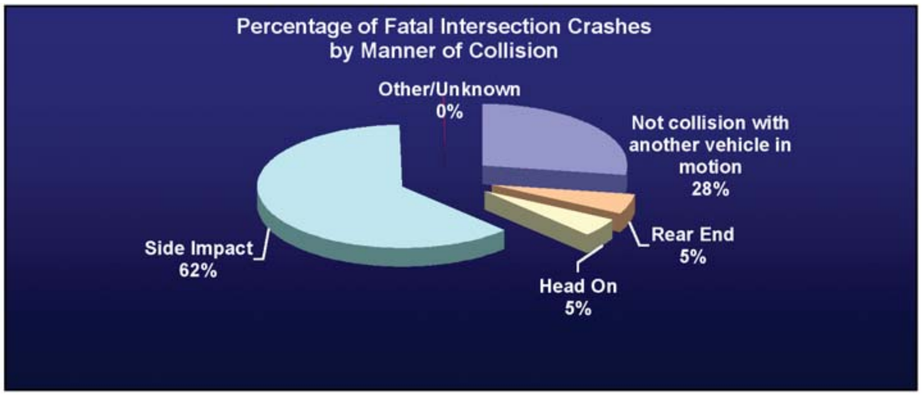

Figure 2

Designing and Operating Intersections for All Users

Transportation engineers must design and operate intersections for all users including

- pedestrians
- bicyclists
- older drivers and younger drivers
- pedestrians of all ages and cognitive and physical abilities/disabilities
- transit/light rail/trolley vehicles
- trucks including loading/unloading maneuvers
- emergency vehicles
- proximate driveways serving commercial properties
- commuters

There *will* be tradeoffs regarding capacity, priority, and operations of an intersection—that is a given. These tradeoffs can only be made when good information is provided to policymakers regarding both dominant and special user populations within and proximate to an intersection.

Tackling the Intersection Safety Problem Requires a Multi-disciplinary Approach

Intersection safety is a complex public health issue that cannot always be solved by making changes in signs and signals, but can be helped by a national comprehensive effort of improved intersection vehicle and pedestrian safety management.

The following actions address ways to achieve substantial reductions in annual crashes, injuries and fatalities:

- **Analyze the reasons for traffic conflicts at intersections.** Multi-disciplinary teams (engineers, enforcement, human factors professionals, etc) are recommended since they can have a broader perspective on crash causes.
- **Engage in innovative and strategic thinking.** Engineers must delicately balance the requirement for efficient traffic movement and congestion reduction and, at the same time, the need to protect vehicle occupants and pedestrians from the consequences of dangerous vehicle maneuvers and unwise pedestrian behavior.
- **Modify the intersection design and operations** based on engineering analysis
- **Identify the safety benefits of reconstruction or construction projects and/or operational changes that are planned at intersections.** Select alternatives that have the greatest safety benefit. Integrate safety evaluations of projects into the planning and design processes.
- **Provide sustained and consistent law enforcement efforts.**
- **All levels of government must play a central role** by providing improved funding, and cooperation with highway and vehicle engineers, health care authorities, law enforcement, national safety organizations, and local citizen safety groups.

Traffic Control Devices: Uses and Misuses

3 ISSUE BRIEFS

Overview

Traffic control devices are signs, signals, pavement markings and other devices placed along highways and streets to move vehicles and pedestrians safely and efficiently. Theses devices are placed in key locations to guide traffic movement, control vehicle speeds and warn of potentially hazardous conditions. They also provide important information to drivers about detours and traffic delays.

Functions of Traffic Control Devices

The main purpose of a traffic control device is to provide information to drivers so they can operate their vehicles safely along a highway or street. The five basic criteria of a traffic control device are to:

- ✦ Fulfill a need;
- ✦ Command attention;
- ✦ Convey a clear, simple meaning;
- ✦ Command respect from road users, and
- ✦ Give adequate time for response.

Signs, signals, pavement markings, cones, barricades and warning lights are designed with dedicated colors, shapes and sizes based on the different functions they provide. They regulate, guide and warn vehicle and pedestrian traffic about road conditions. Uniformity of design (color, shape, size and location) helps drivers to quickly understand the messages of traffic control devices. Consistency is important for driver respect, recognition and proper reaction to the devices.

Characteristics of Uniform Traffic Control Devices

Color. Certain colors are used to trigger instant recognition and reaction; for example, STOP signs are always red. Similarly, signals at intersections must have the same sequence of red/yellow/green to communication stop/warning/go to drivers and pedestrians.

Nighttime visibility. Traffic control devices are made visible under nighttime operating conditions by either being separately lighted or retro-reflectorized so that the light coming from vehicle headlamps is bounced off signs and other devices back to the eyes of drivers.

Daytime visibility. Traffic control devices are designed with highly visible colors or a sharp contrast of messages against a background. Sometimes traffic control devices are lighted even for daytime viewing to draw the attention of drivers to their messages.

Shape and size. Signs have standard shapes and sizes to trigger instant recognition and reaction. For example, STOP signs have an octagonal shape of a particular size that no other sign is permitted to have. There are similar specifications for the shapes and sizes of many other traffic control devices for both permanent and temporary conditions.

Location. Traffic control devices must be placed in locations that provide enough time for all drivers to make the appropriate safe maneuvers, such as entering or departing a road or stopping and turning to avoid conflicts with other vehicles and pedestrians.

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Messages. Traffic control devices are designed with carefully chosen symbol or word messages of specific sizes and content. Locations and functions are then selected in relation to the amount of time that drivers need to detect, read and understand messages to make appropriate vehicle maneuvers.

How to Select the Correct Traffic Control Device

Traffic control devices work in concert with the basic "rules of the road" contained in traffic laws and ordinances, including each states' uniform code that regulates vehicle movements. One example is the "right-of-way" principle that determines which driver has priority when approaching or entering an intersection.

Traffic control devices have undergone a long evolution of design and installation criteria. Current designs and the standards for using them are the result of several decades of scientific investigation and the combined experience of many professional engineers, human behavior and vision researchers and safety policy-makers.

One of the major resources for determining the design and use of traffic control devices is the *Manual on Uniform Traffic Control Devices* (MUTCD). The 2003 Edition of the MUTCD is the national standard applicable to all public roads. The MUTCD provides standards, guidance and application information for signs, markings, traffic signals and other traffic control devices. This document can be found on the Web site: http://mutcd.fhwa.dot.gov/.

Additional basic design guides have been produced by the Institute of Transportation Engineers' such as the *Traffic Engineering Handbook* and *Traffic Control Devices Handbook*. These documents can be ordered through the ITE Bookstore at http://www.ite.org.

Common Problems with Traffic Control Device Placement and Installation

Due to resource constraints, many jurisdictions do not have traffic engineers or traffic engineering technicians on staff. These jurisdictions may rely on personnel that may have an engineering background; however, they may not be specifically trained in traffic engineering. Knowledge of the standards, guidance and applications included in the MUTCD is an essential element in the design, construction, operation and maintenance of roadway segments and intersections. A few of the common problems with traffic control device placement and installation are provided below.

1. **Use of an improper device.** Placing an unwarranted traffic signal where a less restrictive control would be more appropriate may result in unnecessary delays, excessive violations, increased crashes and diversion to less desirable routes such as residential streets.
2. **Improper placement.** A traffic control device at the wrong location may result in the device being seen too late by drivers to safely react (e.g., placing a properly designed sign too far around the bend of a sharp curve).
3. **Wrong color, shape, or size.** Using a color, shape, or size for a sign or other traffic control device that is in conflict with the MUTCD can result in the inability of drivers to detect and comprehend the need to make safe maneuvers and can cause inattention or visibility problems (i.e., "I didn't see the STOP sign.")
4. **Land use, traffic and other changes can cause existing traffic control devices to become obsolete.** As an example, traffic signs that may have controlled the movement of vehicles and pedestrians for years may no longer be effective in doing so.
5. **Lack of signs or other devices to warn drivers and pedestrians of unexpected, potentially hazardous conditions.** For example, neglecting to provide advance warning of an upcoming signal or STOP sign over the top of a steep hill can result in inappropriate braking and steering maneuvers that may result in collisions.
6. **Poor Maintenance.** Signs and pavement markings need to be maintained on a regular basis. Faded signs and pavement markings make them harder for road users to detect and may lead to potentially dangerous situations. For example, faded STOP signs may lead to drivers entering an intersection without stopping.

STOP Signs

Purpose of a STOP Sign

The STOP sign is a regulatory sign that is used when traffic is required to stop. It is a red octagon that has a white border and large white letters that read STOP. At multi-way stop intersections, a small plate is placed below the stop sign to inform the driver of how many approaches are required to stop.

The *Manual of Uniform Traffic Control Devices* (MUTCD) describes STOP signs (R1-1), including applications and placement. STOP signs are used to assign right-of-way at an intersection. Since a STOP sign causes inconvenience to motorists, it should be used only where warranted.

Where Should A STOP Sign Be Installed?

STOP signs should be located where vehicles are to stop or as near to that point as possible. The sign may also be supplemented with a STOP line and/or the word STOP on the pavement.

Where there is a marked crosswalk, the STOP sign should be located approximately 4 ft. in advance of the crosswalk line. When only one STOP sign is used on an intersection approach, it should be on the right side of the roadway.

At wide intersections however, placing an additional sign on the left side of the approach may reduce violations of the STOP sign and the likelihood of right-angle crashes.

If two lanes of traffic exist on an approach, at least one STOP sign should be visible to each lane of traffic.

Under What Conditions Should a Two-Way STOP Sign Be Installed?

Intersections must have one or more of the following conditions for two-way STOP signs to be installed:

- An intersection of a minor and major road, where the application of the normal right-of-way-rule would be hazardous;
- A street enters a highway;
- An unsignalized intersection in a signalized area; and
- Locations where there is a combination of high speed traffic, restricted view, and a previous crash record that indicates a need for STOP sign control.

The advantage of a two-way stop is that the major flows do not have to stop and they incur almost no delay at the intersection (i.e., the majority of the traffic does not have to stop).

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Under What Conditions Should a Four-Way (Multi-way) STOP Sign Be Installed?

Four-way STOP signs are often used at the intersection of two roadways that exhibit approximately equal traffic volumes. The following criteria should be considered:

- A traffic signal is going to be installed and the intersection needs a temporary solution to control the traffic;
- Within 12 months, at least five crashes have occurred at the intersection that could have been prevented by STOP signs. Previous crash records include right- and left-turn collisions, as well as right-angle collisions;
- Minimum traffic and pedestrians volumes;
- 85th percentile major-street vehicle speeds in excess of 40 mph;
- Average minor street vehicle delays of at least 30 sec. during the maximum hour;
- The need to control left-turn conflicts;
- The need to control vehicle/pedestrian conflicts near locations that generate high pedestrian volumes;
- Locations where a road user, after stopping, cannot see conflicting traffic and is not able to safely negotiate the intersection unless conflicting cross traffic is also required to stop; and
- An intersection of two residential neighborhood collector (through) streets of similar design and operating characteristics where multi-way stop control would improve traffic operational characteristics of the intersection.

Failure to Stop at Existing STOP Signs

When there is a history of drivers failing to heed STOP signs that clearly have adequate visibility, the following approaches could be considered:

- Install STOP AHEAD sign;
- Increase size of STOP and STOP AHEAD signs from 30 to 36 in.;
- Install two transverse rumble strips in the approach lane in advance of the STOP AHEAD and before the STOP sign;
- Consider installation of two additional transverse rumble strips to supplement the first two locations;
- Install intersection illumination;
- Consider adding a flashing red beacon in conjunction with the STOP signs or an overhead intersection control beacon with flashing red for the minor street and flashing yellow for the major street;
- Place actuated flashers on the top of a STOP sign. A detector would be in the pavement in advance of STOP sign. As a vehicle approaches, a red flasher would appear. This solution would address the driver expectancy problem and give more attention to the STOP sign; and
- Use of double-indicating left-side STOP sign.

Resources

The MUTCD is located at the following Web site: mutcd.fhwa.dot.gov.

Ellison, James W., P.E. *Case Study: Failure to Stop at a Stop Sign: A Progressive Approach.* **http://www.ite.org/library/IntersectionSafety/ Ellison.pdf.**

5 ISSUE BRIEFS

Traffic Signals

Purpose of Traffic Signals

Traffic signals are used to assign vehicular and pedestrian right-of-way. They are used to promote the orderly movement of vehicular and pedestrian traffic and to prevent excessive delay to waiting traffic.

Traffic signals should not be installed unless one of the warrants specified by the *Manual on Uniform Traffic Control Devices* (MUTCD) has been satisfied. The satisfaction of a warrant is not in itself justification for a signal. A traffic engineering study must be conducted to determine if the traffic signal should be installed.

The installation of a traffic signal requires sound engineering judgment and must balance the following, sometimes conflicting, goals:

- ✦ Moving traffic in an orderly fashion;
- ✦ Minimizing delay to vehicles and pedestrians;
- ✦ Reducing crash-producing conflicts; and
- ✦ Maximizing capacity for each intersection approach.

Where Should A Signal Be Installed?

The MUTCD lists eight warrants for the placement of traffic signals. Readers are encouraged to review Part 4 of the MUTCD for greater specificity regarding signal warrants. Access management considerations and the spacing of signals on arterial roadways are critical elements of system efficiency and operational safety.

The basic question that must be answered is "Will this intersection operate better with or without a traffic signal?"

Advantages of Signals

Warranted traffic signals properly located and operated, usually have one or more of the following advantages:

- ✦ Provide for orderly movement of traffic;
- ✦ Increase traffic capacity of the intersection;
- ✦ Reduce the frequency of certain types of crashes, (e.g. right-angle crashes);
- ✦ Provide for continuous or nearly continuous movement of traffic along a given route; and
- ✦ Interrupt heavy traffic to permit other traffic, vehicular or pedestrian, to cross.

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Factors to Consider When Installing a Signal

A number of factors should be considered when planning to signalize an intersection. These factors include:

- The need to balance delay. Excessive delay results in significant fuel waste and higher motorist costs and air pollution. Solution: signal timing improvements.
- Potential diversion of arterial traffic neighborhood streets. Solution: signal timing improvements.
- Red-light running violations and associated crashes. Solution: Signal Timing, Adequate Yellow Clearance Interval/All-Red Interval.
- Cost. The cost for a signal ranges from $50,000 to more than $200,000 based on the complexity of the intersection and the characteristics of the traffic using it. In addition, the annual operating cost of each signal ranges from $1,000 to $5,000.

Signal Improvements That May Decrease Crashes

- Signal retiming;
- Signal phasing and cycle improvements;
- Review and assure adequacy of yellow change interval/all-red clearance interval for safer travel through the intersection;
- Use of longer visors, louvers, backplates and reflective borders;
- Installation of 12 in. signal lenses;
- Install additional signal heads for increased visibility;
- Provide advance detection on the approaches so that vehicles are not in the dilemma zone when the signal turns yellow;
- Repositioning of signals overhead (via mast arm) instead of post mounted;
- Use of double red signal displays; and
- Remove signals from late night early morning programmed flash.

Table 1, Signalization Countermeasures at Signalized Intersections, includes specific categories of countermeasures such as signal operational improvements, signal hardware and combination signal and other improvements. The table provides the effectiveness in terms of the percentage potential crash reductions that might be experienced, if available. This table is also found in Briefing Sheet No.8, which includes a more comprehensive toolbox of countermeasures for consideration at intersections. Traffic engineers and other transportation professionals can use the information in this Briefing Sheet when the public or an elected or appointed official asks a question such as:

> *What is the range of solutions that might be considered at the signalized intersection of "Maple" and "Elm" streets due to the high number of total crashes and left-turn crashes?" What low-cost improvements can be tried first? If these improvements don't give us a higher degree of safety, what else can we try?*

Traffic engineers will need to consider site-specific environmental, geometric and operational conditions before making a judgment regarding those countermeasures that can be applied to a particular intersection.

Table 1: Signalization Countermeasures at Signalized Intersections

Numbers in [n] indicate references used for Table 1

Numbers prior to the [n] represent the range of % crash reduction that might be expected from implementing a given improvement.

● Countermeasure/Crash Type identified; however no estimate of effectiveness is provided.

		Potential Effectiveness (Percentage Reduction)							
Improvement Type(s)	**Cost**	**Total Crashes**	**Right Angle Crashes**	**Left Turn Crashes**	**Rear-end Crashes**	**Sideswipe**	**Pedestrian**	**Red-Light Running**	**Older Driver**
SIGNAL OPERATIONS IMPROVEMENTS									
Interconnect/Coordinate Traffic Signals; Optimization	Medium	15-17 [1]	25-38 [12]		●			● [2]	
Increase/Modify Clearance Intervals	Low	4-31 [1,9,10]	1-30 [1,9]		●			● [2]	
Improve Signal Timing (General)	Low	10-15 [1]	●	●		●		●	
Add Protected/Permissive LT Phase	Medium	4-10 [1,9]		40-64 [1,9]					
Use Green Arrow/ Protected Left Turns/Movement Signal Phasing	Low	3 [9]		98 [9]					●
Use Split Phases	Low	25 [11]		●	●	●			
Use Leading Pedestrian Interval	Low						5 [8]		
Add Pedestrian Phase	Medium	23-25 [1]					7-60 [1,8]		
Add Left-Turn Phasing to an Existing Signal	Medium	23-48 [6, 12]		63-70 [1]			5 [8]		
Provide Green Extension (Advance Detection)	Variable				●			●	
Install Signal Actuation	Variable				●	●			
Assume Slower Walking Speeds for Pedestrian Signal Timing	Low						●		●
Provide Advance Warning of Signal Changes at Rural Signalized Intersections	Medium	●	●		●			●	
Remove Signals from Late Night/Early Morning Flash	Low	29[9]	80 [9]						
Consider Restricting Right-Turns-on-Red	Low						●		
Consider Installation of Pedestrian Countdown Signals (incremental cost)	Low						●		
Consider Installation of Animated Eye Signals (Incremental cost)	Low						●		
SIGNAL HARDWARE									
Install Larger (12-Inch) Signal Lenses	Low	10-12 [1,9]	48 [9]		●	●		●	●
Install Flashing Beacon at Intersection	Medium	30-38 [1]							
Install Flashing Beacon at Advance of Intersection	Medium	25-28 [1]						● [2]	
Replace Pedestal Mounted Signal with Mast Arm	High	28-43 [12]	●						
Install Backplates on Existing Signals	Low	2-24 [1,9]	7-93 [1,5,9]		●	●		● [2]	●
Optically Programmed Signal Lenses		15-18 [1]						●	
Provide Louvers, Visors, Special Lenses so Drivers are able to View Signals only for their Approach	Low				●	●		●	
Upgrade Signal Controller	Medium	20-22 [1 8, 11]		●	●	●			
Relocate/Shield Signal Hardware in Clear Zone. Signal Hardware Should Not Obstruct Sight Lines.	Medium	[6]	●		●	●			
Install Additional Signal Heads	Medium	10 [9]	42 [9]		●	●		●	●
Install More Overhead Traffic Signals	High	●	●		●			●	●
Provide Two Red-Signal Displays within each Signal Head to Increase Conspicuity of the Red Display	Medium							●[2]	
Use LED Traffic Signal Module.	Medium							● [2]	
Stripe for Left-Turn Lane within Existing Roadway	Low	26 [9]		66 [9]					
Red T-Display	Medium	9 [9]	36 [9]						

Table 1 (continued)
Signalization Countermeasures at Signalized Intersections

		Potential Effectiveness (Percentage Reduction)							
Improvement Type(s)	**Cost**	**Total Crashes**	**Right Angle Crashes**	**Left Turn Crashes**	**Rear-end Crashes**	**Sideswipe**	**Pedestrian**	**Red-Light Running**	**Older Driver**
COMBINATION SIGNAL AND OTHER IMPROVEMENTS									
Construct Left-Turn Lanes with Signal Upgrades	High	●		●	●				
Left-Turn Lane, Signal and NO Turn Phase	High	21-25 [1]		46-54 [1]	●				
Left-Turn Lane, Signal PLUS Turn Phase	High	25-36 [1]		43-45 [1]	●				
Add Left-Turn Phasing AND Turn Lanes to an Existing Signal	High	46-69 [12]	●	●	●				
Removal Signal, Develop a Program to Identify and Remove Unwarranted Signals.	Low	50-53 [1]			●	●			
Install 12" Signal Heads and SIGNAL	Low	11 [9]	36 [9]						

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6 ISSUE BRIEFS

Engineering Countermeasures to Reduce Red-Light Running (RLR)

National Statistics

Crash data from the National Highway Traffic Safety Administration indicates that in 2002, there were 921 fatalities and 178,000 injuries resulting from 207,000 crashes attributable to motorists running red lights at signalized intersections. Crashes involving red-light running are much more likely to cause an injury or a fatality than other intersection crashes. The number of fatal motor vehicle crashes at traffic signals is rising faster than any other type of fatal crash nationwide:

- Red-light running (RLR) has become a national safety problem with a societal cost estimated at $14 billion per year;
- Motorists are more likely to be injured in crashes involving RLR than in other types of crashes. Occupant injuries occurred in 45 percent of the RLR crashes, compared to 30 percent for other crash types; and
- According to a survey conducted by the U.S. Department of Transportation and the American Trauma Society, 63 percent of Americans witness a RLR incident more than once a week. One in three Americans knows someone who has been injured or killed because of a red-light runner

When does RLR occur?

RLR occurs when a driver enters an intersection after the traffic signal has turned red. The reasons that motorists run red lights are varied and are both intentional—"in a hurry and didn't want to wait"—and unintentional—"my vision to the signal was blocked." According to survey research, drivers believe RLR is often an intentional act with few legal consequences. The traditional way of enforcing this violation is to station a patrol vehicle near an intersection. This method is dangerous for the officer, expensive to localities and drains valuable police resources.

Engineering Countermeasures to Reduce RLR

ITE and the Federal Highway Administration developed a publication entitled *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running: An Informational Report*. The principal objective of the publication is to identify the engineering design and whether operational features of an intersection should be upgraded as necessary to discourage RLR. The engineering countermeasures can be grouped into four distinct areas:

- Improving signal visibility/conspicuity;
- Increasing the likelihood of stopping;
- Addressing intentional violations; and
- Eliminating the need to stop.

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Table 1: Summary of Engineering Countermeasures to Reduce Red-Light Running

Increase Signal Visibility/Conspicuity	Increase Likelihood of Stopping	Address Intentional Violations	Eliminate Need to Stop
Placement/Number of Signal Heads	Signal Ahead Signs	Signal Optimization	Unwarranted Signals
Size of Signal Display	Advance Warning Flashers	Signal-Cycle Length	Roundabout Intersection Design
Line of Sight: Programmable Lens Signals	Rumble Strips	Yellow-Change Interval	
Line of Sight: Visors/Louvers	Left-Turn Signal Sign	All-Red Clearance Interval	
LED Signal Lenses	Pavement Surface Condition	Dilemma Zone Protection	
Backplates			

Table 1 summarizes the countermeasures that can be considered under each of the countermeasure groupings identified above. A brief description of each countermeasure follows. In addition, Figure 1, *Sample Assessment Sheet*, on page 4, shows the types of information that an engineer or an engineering technician should evaluate in the field. A separate assessment sheet would be completed for intersection approach.

Descriptions of Summary Items

Increase Signal Visibility/Conspicuity

Placement and Number of Signal Heads. Overhead-signal displays help to overcome the three most significant obstacles posed by pole-mounted signal heads, which are: (1) they generally do not provide good conspicuity, (2) mounting locations may not provide a display with clear meaning and (3) motorists' line-of-sight blockage to the signal head due to other vehicles, particularly trucks, in the traffic stream. Studies have shown significant reduction in accidents attributed to replacement of pole-mounted signal heads with overhead-signal heads.

Signal for Each Approach Lane. Section 4D.15 of the *Manual on Uniform Traffic Control Devices* (MUTCD) only requires that "a minimum of two signal faces shall be provided for the major movement on the approach." Under this standard, it would be acceptable to have only two signals on an approach with three or more through lanes. When a signal is positioned such that it is over the middle of the lane, it is in the center of the motorist's cone of vision, thereby increasing its visibility. The additional signal head further increases the likelihood that a motorist will see the signal display for the approach.

Size of Signal Displays. 12-in. signal lenses should be considered for all signals, and especially those displaying red indications, to increase signal visibility.

Programmable Lens Signals. The optically programmed or visibility-limited signals limit the field of view of a signal. They allow greater definition and accuracy of the field of view. The MUTCD speaks of visibility-limited signals mostly with regard to left-turning traffic at an intersection. The MUTCD permits the use of visibility limited signal faces in situations where the road user could be misdirected, particularly at skewed or closely-spaced intersections when the road user sees the signal indications intended for other approaches before seeing the signal indications for their own approach.

Louvers. Louvers are used to avoid confusion on intersection approaches where approaching motorists may be able to see the signal indication for another approach, typically due to a skewed approach angle at the intersection. The purpose of a louver is to block the view of the signal from another approach.

LED Signal Lenses. LED units are used for three main reasons: they are very energy efficient, are brighter than incandescent bulbs and have a longer lif e increasing the replacement interval. LED signals may be noticeably brighter and more conspicuous than an adjacent signal with the incandescent bulb. LED traffic signal modules have service lives of 6 to 10 years as compared to incandescent bulbs that have a life expectancy of only 12 to 15 months. However, research regarding the impacts of LED signal lenses on crash rates has not been undertaken. There is a belief that LEDs are brighter and last longer, and therefore would provide safety benefits but this has not been quantified. Some studies have found that LED's tend to loose brightness over time instead of exhibiting an immediate failure.

Backplates. Backplates are used to improve the signal visibility by providing a black background around the signals, thereby enhancing the contrast. They are particularly useful for signals oriented in an east-west direction to counteract the glare effect of the rising and setting sun or areas of visually complex backgrounds. A retroreflective yellow border strip around the outside perimeter of signal backplates has been found to significantly reduce night-time crashes at signals and also helps drivers identify an intersection as signalized during a power failure.

Increase Likelihood of Stopping

Signal Ahead Signs. The MUTCD requires an advance traffic control warning sign when "the primary traffic-control device is not visible from a sufficient distance to permit the road user to respond to the device."

Advance Warning Flashers. The purpose of an advance-warning flasher (AWF) is to forewarn the driver when a traffic signal on his/her approach is about to change to the yellow and then the red phase.

Rumble Strips. Rumble strips are a series of intermittent, narrow, transverse areas of rough-textured, slightly raised, or depressed road surface. The rumble strips provide an audible and a vibro-tactile warning to the driver. When coupled with the SIGNAL AHEAD warning sign and also the pavement marking word message—SIGNAL AHEAD—the rumble strips can be effective in alerting drivers of a signal with limited sight distance.

Left-Turn Signal Sign. The LEFT TURN SIGNAL sign provides additional information not given in the actual signal indication to the driver by specifying the control device for different intersection movements. The MUTCD requires this sign to accompany a separate signal face controlling a "protected-only mode" left turn movement (turn only allowed on green arrow) when that signal face uses a red ball indication. If the signal face uses a red left-arrow indication, this sign is not to be used.

Pavement Surface Condition. As a vehicle approaches a signalized intersection and slows to stop for a red light, it may be unable to stop due to poor pavement friction and as a result, proceed into the intersection. Countermeasures to improve skid resistance include asphalt mixture (type and gradation of aggregate as well as asphalt content), pavement overlays and pavement grooving. Additionally, countermeasures such as the use of a SLIPPERY WHEN WET sign with a supplemental Advisory Speed Plate for a lower advisory speed can be considered.

Address Intentional Violations

Signal Optimization. Interconnected signal systems provide coordination between adjacent signals and are proven to reduce stops, reduce delays, decrease accidents, increase average travel speeds and decrease emissions. If drivers are given the best signal coordination practical, they may not be as compelled to beat or run a red signal.

Signal Cycle Length. Proper timing of signal-cycle lengths can reduce driver frustration that might result from unjustified short or long cycle lengths. Longer cycle lengths means fewer cycles per hour and therefore fewer yellow-change intervals per hour and thus can reduce the number of opportunities for traffic-signal violations. On the other hand, signal cycles that are excessively long can encourage RLR because drivers do not want to have to wait several minutes for the next green interval.

Yellow Change Interval. A properly timed yellow interval is *essential* to reduce signal violations. An improperly timed yellow interval may cause vehicles to violate the signal. If the yellow interval is not long enough for the conditions at the intersection, the motorist may violate the signal. Motorists have some expectancy of what the yellow interval should be and base their decisions to proceed or stop based on their past experiences. In order to reduce signal violations, the engineer should ensure that the yellow interval is adequate for the conditions at the intersection and the expectations of the motorists.

All-Red Clearance Interval. An all-red interval is that portion of a traffic signal cycle where all approaches have a red-signal display. If used, the all-red interval follows the yellow-change interval and precedes the next conflicting green interval. The purpose of the all-red interval is to allow time for vehicles that entered the intersection during the yellow-change interval to clear the intersection before the traffic-signal display for the conflicting approaches turns to green.

Dilemma Zone Protection. The "dilemma zone" has been defined recently to be the area in which it may be difficult for a driver to decide whether to stop or proceed through an intersection at the onset of the yellow-signal indication. It is also referred to as the "option zone" or the "zone of indecision" One potential countermeasure to reduce red-light running is to reduce the likelihood that a vehicle will be in the dilemma zone at the onset of the yellow interval. This can be accomplished by placing vehicle detectors at the dilemma zone. They detect if a car is at the dilemma zone immediately before the onset of the yellow interval. If a vehicle is there, the green interval can be extended so that the vehicle can travel through the dilemma zone and prevent the onset of the yellow while in the dilemma zone.

Eliminate Need to Stop

Unwarranted Signals. If there is a high incidence of RLR violations, this may be because the traffic signal is perceived as not being necessary and does not command the respect of the motoring public. Sometimes signals are installed for reasons that dissipate over time. For instance, traffic volume may decrease due to changing land-use patterns or the creation of alternative routes. The removal of a traffic signal should be based on an engineering study. Factors to be considered are included in ITE's *Traffic Control Devices Handbook*. If a signal is eliminated, the traffic engineer must continue to monitor the intersection for potential increases in crashes.

Roundabout Intersection Design. When a roundabout replaces a signalized intersection, the RLR problem is obviously eliminated. Readers should consult the Roundabout Safety Briefing Sheet for further information.

References

1. Institute of Transportation Engineers, Publication IR-115, 2003. *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running: An Informational Report* http://safety.fhwa.dot.gov/rlr/rlrreport/RLRbook.pdf

2. J. Bonneson, M. Brewer, and K. Zimmerman, *Engineering Countermeasures to Reduce Red-Light Running, FHWA –TX-03/4027-2 and, 04/4196-1 (Washington, DC: Federal Highway Administration, 2002)* http://tcd.tamu.edu/Documents/4196-1.pdf http://tcd.tamu.edu/Documents/4027-2.pdf

Sample Assessment Sheet: Engineering Countermeasures to Reduce Red-Light Running

Intersection: ____________________ with ____________________
Approach Name: ____________________ Direction Heading: Lanes at Intersection: ____________

CHECK SIGNAL CONTROL PARAMETERS

Yellow Interval	Y = ________seconds		Approach speed	V= ________mph
All-red Interval	AR= ________seconds		Cross street width	W= ________feet
Grade (as decimal)	g = ________(uphill is positive)		Cycle length	C= ________seconds

Calculate the needed change period (CP) for this approach using agency practice or the following equation:

$$CP = 1.0 + \frac{1.47 * V}{(10 + 64.4g)} + \frac{W + 20}{1.47 * V}$$

Calculated yellow: ____________ Calculated all-red: ____________ Are yellow and all-red adequate? Y N

CHECK SIGNAL VISIBILITY

Type of signal mounting: ________ Mast Arm ______ Span Wire________ Pole ________
Can signal faces on other approaches be seen? Y N
Is anything blocking the view of the signals (e.g. utility lines or foliage)? ____________________

Measurement		Reference	Is Existing Adequate?
Distance upstream signal is visible on approach	feet	MUTCD Table 4-1	Y N
Distance from stop bar to signal	feet	MUTCD Figure 4D-2	Y N
Diameter of signal lenses	8 inch 12 inch		
Near side signal	Y N		
Number of signals		Per MUTCD, at least 2 signals for the major movement	Y N

CHECK SIGNAL CONSPICUITY

Is there visual clutter at the intersection that could detract from the signal? Y N At night? Y N
Are the signal indications confusing? ____________________ Could glare affect signal? ____________
Is the left turn signal discernible from the through signal? ____________________

OPTIONS FOR CONSIDERATION

- ❑ Conduct signal warranting study
- ❑ Change yellow or red interval
- ❑ Provide dilemma-zone protection
- ❑ Modify cycle length
- ❑ Coordinate signal
- ❑ Remove/relocate sight obstruction
- ❑ Install double red signal
- ❑ Relocate signal
- ❑ Change signal mounting
- ❑ Install additional signals
- ❑ Install near-side signal
- ❑ Install Advance Warning Flashers
- ❑ Install larger signal lenses
- ❑ Use programmable lenses
- ❑ Illuminate intersection
- ❑ Install backplates
- ❑ Install LEDs
- ❑ Install rumble strips on approach
- ❑ Use visors or louvers
- ❑ Install LEFT TURN SIGNAL sign
- ❑ Install SIGNAL AHEAD sign

Using Red-Light Cameras to Reduce Red-Light Running (RLR)

Red-Light Running Problem

Crash data from the National Highway Traffic Safety Administration indicates that in the year 2002, there were **921** fatalities and **178,000** injuries resulting from **207,000** crashes attributable to motorists running red lights at signalized intersections. The number of fatal motor vehicle crashes at traffic signals is rising faster than any other type of fatal crash nationwide.

Putting It in Perspective

- RLR has become a national safety problem, with a societal cost estimated at $14 billion per year.
- Motorists are more likely to be injured in crashes involving RLR than in other types of crashes. Occupant injuries occurred in 45 percent of the RLR crashes, compared to 30 percent in other crash types.
- According to a survey conducted by the U.S. Department of Transportation and American Trauma Society, 63 percent of Americans witness a RLR incident more than once a week. One in three Americans knows someone who has been injured or killed because of a red-light runner.

When does RLR occur?

RLR occurs when a driver enters an intersection after the traffic signal has turned red. The reasons that motorists run red lights are varied and are both intentional ("in a hurry and didn't want to wait") and unintentional ("my vision to the signal was blocked"). According to survey research, drivers believe RLR is often an intentional act with few legal consequences. The traditional way of enforcing this violation is to station a patrol vehicle near an intersection. This method is dangerous for the officer, expensive to localities and drains valuable police resources.

Crashes resulting from red-light running are much more likely to cause an injury or fatality than other intersection crashes.

7 ISSUE BRIEFS

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Solution: Red-light camera technology can make intersections safer.

The solution to the RLR problem involves a combination of engineering, education and enforcement measures. Research suggests that "intentional" red-light runners, who account for a significant percentage of red-light runners, are most affected by enforcement countermeasures.

What are red-light cameras?

Red-light cameras encompass a system that allows for automated enforcement of RLR. It includes embedded vehicle detectors wired to signal controllers that can detect if a vehicle has entered the intersection when the signal is red. Some systems also record the speed of the vehicles as they approach and enter the intersection. Roadside mounted cameras record images (either film or digital) of the violation. Depending upon the camera placement and agency's policy, front or rear images of the vehicle are processed. The images are reviewed at a central location and if the violation is confirmed by law enforcement, then a citation is issued to the owner of the vehicle. In some jurisdictions, the owner can challenge the citation if he or she was not the driver.

The usage of automated RLR enforcement is increasing with more than 90 jurisdictions in 15 states deploying one or more camera systems.

Successful applications: Research demonstrates crash reductions

Based on a literature review and jurisdiction survey reported in the National Cooperative Highway Research Program Synthesis 310, *Impact of Red Light Camera Enforcement on Crash Experience*, a majority of jurisdictions reported downward trends in RLR-related violations and crashes, especially the more severe kind, because of red-light cameras. For example:

- In Fairfax, VA, violations were reduced by 41 percent after the first year of camera enforcement;
- San Francisco and Los Angeles, CA realized a 68- and 92-percent reduction in violations, respectively;
- In Charlotte, NC, RLR violations were reduced by more than 70 percent during the first year of operation; and
- In Oxnard, CA, the number of crashes at all signalized intersections was reduced by 7 percent and the number of injury crashes was reduced by 29 percent.

Automated enforcement can be an effective and reliable tool to help reduce the number of RLR violations and associated crashes.

Proper Implementation of RLR Cameras

The primary purpose of RLR cameras is to reduce RLR violations and thereby reduce RLR-related crashes. RLR-camera programs should not be implemented to increase revenue from citations. According to the Federal Highway Administration's *Guidance for Using Red-Light Cameras*, the following critical elements should be considered while installing red-light camera systems:

- Conduct an engineering study before considering camera installation;
- Evaluate effective engineering and education alternatives before considering photo-enforcement;
- Make sure the red-light camera program is engineered and installed properly;
- Measure, document and make safety results available;
- Ensure complete oversight and supervision by public agencies;
- Avoid compensating vendors based on number of citations; and
- Include an ongoing photo-enforcement public education program.

Resources

1. *Engineering Countermeasures to Reduce Red-Light Running.* Washington, DC: ITE, 2003. http://safety.fhwa.dot.gov/rlr/rlrreport/RLRbook.pdf

2. *Guidance for Using Red Light Cameras.* This FHWA publication provides information to state and local agencies on how to initiate and operate an appropriate red light camera program. Call 202-366-5915 to order Publications No. FHWA-SA-03-018, or visit http://www.nhtsa.dot.gov/people/injury/enforce/guidance03/Guidancereport.pdf

3. *Impact of Red Light Camera Enforcement on Crash Experience*. This NCHRP synthesis examines what impact camera enforcement has had on crashes and crash severity, based on published literature and information from jurisdictions. http://gulliver.trb.org/publications/nchrp/nchrp_syn_310.pdf

Toolbox of Countermeasures and Their Potential Effectiveness to Make Intersections Safer

8 ISSUE BRIEFS

Introduction

Studies included in the NCHRP 17-18 (3), Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, as well as in other research by governmental entities have produced estimates of crash reductions that might be expected if a specified improvement or group of improvements are implemented. Three tables have been developed that attempt to summarize some of the available information. Readers will note that, by and large, there may be little consensus regarding the value of crash reduction factors for a number of countermeasures. The transportation engineering discipline needs to develop a base of statistically sound before-and-after studies for extended periods of time to overcome the deficit in countermeasure effectiveness data.

Use of the Tabular Data

The data in this briefing sheet represent a number of countermeasure effectiveness studies and includes ranges of effectiveness realized from one or more sources. Readers are encouraged to obtain and review original source documents for more detailed information. It must be emphasized that the potential effectiveness values, for expample percentage reduction in crashes, represent order-of-magnitude estimates only. Traffic engineers need to consider site-specific environmental, geometric and operational conditions before making a judgment regarding those countermeasures that will be applied to an intersection.

Traffic engineers and other transportation professionals can use the information contained in this briefing sheet when the public or an elected or appointed official asks a question such as:

> *What is the range of solutions that might be considered at the signalized intersection of Maple and Elm streets due to the high number of total crashes and left-turn crashes?" What low-cost improvements can be tried first? If these improvements do not give us a higher degree of safety, what else can we try?*

The countermeasure effectiveness tables in this briefing package include:

- **Table 1: Signalization Countermeasures at Signalized Intersections.** Specific categories of countermeasures included in this table are signal timing and phasing improvements, signal hardware and combination signal and other improvements.

- **Table 2: Geometric Countermeasures at Unsignalized Intersections.** Specific categories of countermeasures included in this table are left-turn treatments, right-turn treatments and other geometric improvements.

- **Table 3: Signs/Markings/Operational Countermeasures (Applicability Notes for Signalized and/or Unsignalized Intersections).** Specific categories of countermeasures included in this table are: signs, pavement markings and modifications, and regulatory, lighting and operational improvements.

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Table 1: Signalization Countermeasures at Signalized Intersections

Numbers in [n] indicate references used

Numbers prior to the [n] represent the range of % crash reduction that might be expected from implementing a given improvement.

● **Countermeasure/Crash Type identified; however no estimate of effectiveness is provided.**

		Potential Effectiveness (Percentage Reduction)							
Improvement Type(s)	**Cost**	**Total Crashes**	**Right Angle Crashes**	**Left Turn Crashes**	**Rear-end Crashes**	**Sideswipe**	**Pedestrian**	**Red-Light Running**	**Older Driver**
SIGNAL OPERATIONS IMPROVEMENTS									
Interconnect/Coordinate Traffic Signals; Optimization	Medium	15-17 [1]	25-38 [12]		●			● [2]	
Increase/Modify Clearance Intervals	Low	4-31 [1,9,10]	1-30 [1,9]		●			● [2]	
Improve Signal Timing (General)	Low	10-15 [1]	●	●		●		●	
Add Protected/Permissive LT Phase	Medium	4-10 [1,9]		40-64 [1,9]					
Use Green Arrow/ Protected Left Turns/Movement Signal Phasing	Low	3 [9]		98 [9]					●
Use Split Phases	Low	25 [11]		●	●	●			
Use Leading Pedestrian Interval	Low						5 [8]		
Add Pedestrian Phase	Medium	23-25 [1]					7-60 [1,8]		
Add Left-Turn Phasing to an Existing Signal	Medium	23-48 [6, 12]		63-70 [1]			5 [8]		
Provide Green Extension (Advance Detection)	Variable				●			●	
Install Signal Actuation	Variable				●	●			
Assume Slower Walking Speeds for Pedestrian Signal Timing	Low						●		●
Provide Advance Warning of Signal Changes at Rural Signalized Intersections	Medium	●	●		●			●	
Remove Signals from Late Night/Early Morning Flash	Low	29 [9]	80 [9]						
Consider Restricting Right-Turns-on-Red	Low						●		
Consider Installation of Pedestrian Countdown Signals (incremental cost)	Low						●		
Consider Installation of Animated Eye Signals (Incremental cost)	Low						●		
SIGNAL HARDWARE									
Install Larger (12-Inch) Signal Lenses	Low	10-12 [1,9]	48 [9]		●	●		●	●
Install Flashing Beacon at Intersection	Medium	30-38 [1]							
Install Flashing Beacon at Advance of Intersection	Medium	25-28 [1]						● [2]	
Replace Pedestal Mounted Signal with Mast Arm	High	28-43 [12]	●						
Install Backplates on Existing Signals	Low	2-24 [1,9]	7-93 [1,5,9]		●	●		● [2]	●
Optically Programmed Signal Lenses		15-18 [1]						●	
Provide Louvers, Visors, Special Lenses so Drivers are able to View Signals only for their Approach	Low				●	●		●	
Upgrade Signal Controller	Medium	20-22 [1 8, 11]		●	●	●			
Relocate/Shield Signal Hardware in Clear Zone. Signal Hardware Should Not Obstruct Sight Lines.	Medium	[6]	●		●	●			
Install Additional Signal Heads	Medium	10 [9]	42 [9]		●	●		●	●
Install More Overhead Traffic Signals	High	●	●		●			●	●
Provide Two Red-Signal Displays within each Signal Head to Increase Conspicuity of the Red Display	Medium							● [2]	
Use LED Traffic Signal Module.	Medium							● [2]	
Stripe for Left-Turn Lane within Existing Roadway	Low	26 [9]		66 [9]					
Red T-Display	Medium	9 [9]	36 [9]						

Table 1 (continued)
Signalization Countermeasures at Signalized Intersections

		Potential Effectiveness (Percentage Reduction)							
Improvement Type(s)	**Cost**	**Total Crashes**	**Right Angle Crashes**	**Left Turn Crashes**	**Rear-end Crashes**	**Sideswipe**	**Pedestrian**	**Red-Light Running**	**Older Driver**
COMBINATION SIGNAL AND OTHER IMPROVEMENTS									
Construct Left-Turn Lanes with Signal Upgrades	High	●		●	●				
Left-Turn Lane, Signal and NO Turn Phase	High	21-25 [1]		46-54 [1]	●				
Left-Turn Lane, Signal PLUS Turn Phase	High	25-36 [1]		43-45 [1]	●				
Add Left-Turn Phasing AND Turn Lanes to an Existing Signal	High	46-69 [12]	●	●	●				
Removal Signal, Develop a Program to Identify and Remove Unwarranted Signals.	Low	50-53 [1]			●	●			
Install 12" Signal Heads and SIGNAL	Low	11 [9]	36 [9]						

Table 2:
Geometric Countermeasures at Unsignalized Intersections

		Potential Effectiveness (Percentage Reduction)					
Improvement Type/Special User	**Cost**	**Total Crashes**	**Right Angle**	**Left Turn**	**Rear-end**	**Sideswipe**	**Older Driver**
LEFT TURN TREATMENTS							
Add Left-Turn Lane, No Signal	Medium-High	25-41 [1,9]		50-86 [1,9]			
Provide Separate Left-Turn Lane, One Major Road Approach, and 3-Leg Intersection.	Medium	44/rural 33/urban [5]			●		
Provide Separate Left-Turn Lane, One Major Road Approach, and 4-Leg Intersection.	Medium	28/rural 27/urban [5]			●		
Provide Separate Left-Turn Lane, 2 Major Road Approaches	High	42 [5]					
Provide Adequate Length Turn Lane	Medium	15-30 [1,7,10]			●		
Provide Indirect Left Turns	Variable		●	●	●		
Provide Offset Left Lanes	Variable	●		●	●	●	● [1]
Provide Left-Turn Acceleration Lane at Divided Highway Intersections	Medium-High				●		
Add Continuous Left-Turn Lanes	High	● [1]					
RIGHT-TURN TREATMENTS							
Provide Right-Turn Lane, One Major Approach, on Rural 4-Lane, Intersection	Medium	14 [5, 10]			●		
Exclusive Right-Turn Lanes, Two Major Approaches, on Rural 4-Lane, Intersection	Variable	14-27 [5]			●		
Provide Right-Turn Acceleration Lanes	Variable	●			●	●	
Provide Longer Right-Turn Lane	Variable	●					
Provide Offset Right-Turn Lane	Variable	●		●			● [1]
Add Right-Turn Lane	Medium	24-30 [1]					

Table 2 (continued on page 4)

Table 2 (continued)
Geometric Countermeasures at Unsignalized Intersections

		Potential Effectiveness (Percentage Reduction)					
Improvement Type/Special User	**Cost**	**Total Crashes**	**Right Angle**	**Left Turn**	**Rear-end**	**Sideswipe**	**Older Driver**
OTHER/GEOMETRIC IMPROVEMENTS							
Shoulder Bypass Lanes; Rural Intersections.	Low				●		
Move Intersection Away from Curve.	High	25 [1,7,8]	●		●	●	
Horizontal/Vertical Realignment of Approaches.	High	● [7]					
Raised Medians Near Major Intersections.	Medium-High	25 [6,1,7,8]					
Continuous Two-Way Left-Turn Lanes to Separate Left Turn and Through Traffic	High	30-40 [1,7,8]			●		
Convert 4-Leg to Two, 2-T Intersections	High	57 [5,10]					
Convert Two-T Intersections to One 4-Leg.	High	● [7]					
Close or Relocate High Risk Intersections	Variable	100 [7]					
Full Width Paved Shoulders. No Shoulder Width Less than 8 ft.	Variable	2.8% per ft. of additional shoulder width [7]			●		
Install Splitter Islands on the Minor Road Approach where the Intersection or STOP Sign is not Visible to Motorists.	Medium	NCOE [7]					
Remove Intersection Skew Angle (of less than 80 degrees); Realign Intersection	High	40-50, [1,10]					
Increase Curb Turning/Edge of Pavement Radii	Medium	15-21 [1,7]			●		● [1]
Widen Approaches to Handle Turns	Medium	[7]			●	●	
Roundabouts at Appropriate Locations	High	38, Total Crashes 76, Injuries 90, Fatalities [7]					
Clear Sight Triangle on Stop or Yield Controlled Approaches	Low	● [7]	●				
Clear Sight Triangle in the Medians of Divided Highways Near Intersections	Low	● [7]					

● **Countermeasure/Crash Type identified; however no estimate of effectiveness is provided.**

Table 3: Signs/Markings/Operational Countermeasures Applicability Noted for Signalized and/or Unsignalized Intersections

			Potential Effectiveness (Percentage Reduction)						
Improvement Type	**Applicability**	**Cost**	**Total Crashes**	**Right Angle**	**Rear End**	**Side-swipe**	**Pedestrian**	**Red-Light Running**	**Older Adults**
SIGNS									
Install SIGNAL AHEAD Sign	Signalized Intersection	Low	3-40 [7,9, 11]	35 [9]	●	●		● [2]	
Install LEFT TURN Signal Sign	Signalized Intersection	Low						● [2]	
Install SLIPPERY WHEN WET Sign	Signalized Intersection	Low						● [2]	
Enhanced Signing and Delineation	Unsignalized Intersection	Low	● [7]	●	●				
Supplementary STOP Signs Mounted Over the Roadway	Unsignalized Intersection	Low	● [7]	●					
Install YIELD TO PEDESTRIAN Sign	Undefined	Low					10 [8]		
PAVEMENT MARKINGS/MODIFICATIONS									
Install Raised Pavement Markings	Undefined		6-13 [1] 20-30 (Night) 20-46 (Wet, Night)						●
Use Wider Pavement Markings	Undefined								●
Install Rumble Strips on Intersection Approaches	Undefined		2-44 [1]; NCOE [7]	●					

Table 3 (continued)
Signs/Markings/Operational Countermeasures Applicability Noted for Signalized and/or Unsignalized Intersections

			Potential Effectiveness (Percentage Reduction)						
Improvement Type	**Applicability**	**Cost**	**Total Crashes**	**Right Angle**	**Rear End**	**Side-swipe**	**Pedestrian**	**Red-Light Running**	**Older Adults**
PAVEMENT MARKINGS/MODIFICATIONS (continued)									
Resurfacing	Undefined		7-59 [1]; W, 40-54 [1]						
Add Stop Bars/Crosswalks	Signalized Intersection		10-25 [10]	●	●	●			
Install Raised Crosswalk	Undefined						8 [8]		
Groove Pavement for Skid Resistance	Undefined		1-65 [1]; 25 [11] Wet- 42-75 [1]			●			
Angled Median Crosswalk	Undefined	Medium	12 [8]						
Add Stop bars, Wider Stop Bar on the Minor Road Approach; and Short Segments of Centerlines	Undefined		10-27 [1,9, 11,13]	● [5] 47 [9]					
Move Vehicle Stop Line Farther Back from Crosswalk AND Add Sign STOP HERE FOR PEDESTRIANS	Signalized Intersection	Low					●		
STOP AHEAD and STOP Messages on Pavement	Undefined	Low	6 [9]	● [5] 30 [9]					
Add Centerlines, Stop Bars and Replace 24 in. STOP Signs	Unsignalized	Low	45 [9]	67 [9]					
Double Indicated STOP Signs	Unsignalized	Low	11 [9]	36 [9]					
Add Centerlines and Move Stop Bars to Extended Curb Lines.	Unsignalized	Low	29 [9]	24 [9]					
Add Centerlines, Move STOP Bars to Extend Curb Lines, and Add Double-Indicated STOP Signs	Unsignalized	Low	9 [9]	0 [9]					
Provide Dashed Pavement Lining to Guide Left-Turning Vehicles Through Selected Intersections	Undefined	Low	● [1]						
Signed and Marked Crosswalks. For Greatest Effectiveness, Include Curb Ramps, Curb Extensions	Unsignalized Intersection	Low	25-48 [1]				●		
Use Rumble Strips Prior to Rural STOP Signs	Rural, Unsignalized Intersection	Low	35 [8]						
Rumble Strips and SIGNAL AHEAD Warning Sign and Pavement Marking with Message SIGNAL AHEAD	Signalized Intersection	Medium						● [2]	
Replace YIELD Signs with STOP Signs	Unsignalized	Low	29 [9]	9 [9]					
REGULATORY									
2-Way to Multi-Way Stop	Unsignalized Intersection	Low	53-74 [4,9,11]	84 [9]	●	●			
Restrict/Eliminate RTOR	Signalized Intersection	Low	20-25 [1]	●	●		●		
Eliminate Parking that Restricts Sight Distance	Undefined	Low	8-90 [1, 7, 11]						
Restrict Driveways Near Intersections; Right Turn In and Out Movements Only	Unsignalized Intersection Signalized Intersection	Low	● [1,7]						
Allow Left Turns In, but Prohibit Left Turns Out at Selected Access Points (Access Management)	Unsignalized Intersection Signalized Intersection	Low	● [1,7]						

Table 3 (continued on page 6)

Table 3 (continued)
Signs/Markings/Operational Countermeasures Applicability Noted for Signalized and/or Unsignalized Intersections

			Potential Effectiveness (Percentage Reduction)						
Improvement Type	**Applicability**	**Cost**	**Total Crashes**	**Right Angle**	**Rear End**	**Side-swipe**	**Pedestrian**	**Red-Light Running**	**Older Adults**
LIGHTING									
Improve Visibility of the Intersection by Providing Lighting	Unsignalized Intersection Signalized Intersection	Medium	19-75 [1, 7, 8] Night- 18-70 [1]	●	●				●
Improve Visibility of the Existing Rural Intersections and Urban Corridors by Providing Lighting	Undefined	Medium	25-50 [1] N-42-50 [1]						●
OPERATIONAL									
Add Signal to a Unsignalized Intersection when Warranted	Unsignalized	High	20-45 [1,9]	68 [9]					
Add Raised Medians Near Intersections	Undefined		25 [1,10,12]				●		
Install Flashing Beacons	Unsignalized Intersection		● [1]	●					
Improve Access Control Near Intersections	Unsignalized Intersection Signalized Intersection		● [1]						
Refuge Islands	Undefined						56 [8]		
Pedestrian Overpasses/Underpasses	Unsignalized Intersection Midblock	High					13 [8] 90-95 [1]		
Mid-block Traffic Signal	Midblock	High					52 [8]		
Far-side Bus Stops	Unsignalized Intersection Signalized Intersection						1 [8]		
Install Raised Medians	Unsignalized Intersection Signalized Intersection	Medium					69 [8]		
Speed Reduction and Enforcement	Unsignalized Intersection Signalized Intersection	High					70 [8]		
Cut Back Vegetation, Embankments as Far as Possible at Existing Stop-Signed Controlled Intersections	Unsignalized Intersection Signalized Intersection		[5]						

● **Countermeasure/Crash Type identified; however no estimate of effectiveness is provided.**

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9 ISSUE BRIEFS

Pedestrian Safety at Intersections

Although intersections represent a very small percentage of U.S. surface road mileage, more than one in five pedestrian deaths is the result of a collision with a vehicle at an intersection. Annually, an average of 5,381 pedestrians died in traffic crashes between 1990 and 2002. [1]

Overview

The Year 2002 National Highway Traffic Safety Administration's pedestrian crash facts are as follows:

- ✦ 4,808 pedestrians were killed;
- ✦ 1,046 pedestrians, or 22 percent, of all pedestrians were killed at intersections;
- ✦ 71,000 pedestrians were injured;
- ✦ 31,000 pedestrians, or 44 percent, of all pedestrians were injured at intersections;
- ✦ A pedestrian is **killed or injured** in an intersection traffic crash every 16 minutes;
- ✦ 13 percent of pedestrian fatalities at intersections occur at night (between the hours of 6:00 p.m. and 6:00 a.m.);
- ✦ Pedestrians involved in crashes are more likely to be killed as vehicle speed increases. The fatality rate for a pedestrian hit by a car at 20 mph is 5 percent. The fatality rate rises to 80 percent when vehicle speed is increased to 40 mph; [2]
- ✦ People aged 70 and older account for 17 percent of all pedestrian fatalities;
- ✦ People aged 65 and older have about 2.5 as many pedestrian deaths per 100,000 people as younger groups; and
- ✦ 36 percent of pedestrian deaths among those aged 65 and older occurred at intersections. This compares to 20 percent for people of other ages.

Pedestrian Safety Problems at Intersections

Types of hazardous intersections for pedestrian crossings include high-volume, high-speed and multi-lane intersections with complex signal phasing or without any traffic control at all.

Pedestrians are at risk even at simple STOP- or YIELD-sign intersections because of the common disregard of traffic control devices by both motorists and pedestrians.

Roadways need to be designed to accommodate the needs of all road users. Roadway modifications that include widening streets, adding lanes and using traffic engineering solutions that increase vehicular efficiency can decrease pedestrian safety if not properly considered.

Many pedestrians, especially in large urban areas, violate pedestrian traffic control and place themselves at risk for collisions with motor vehicles. [3] About one-third of fatal crashes involving pedestrians are the result of pedestrians disobeying intersection traffic control or making misjudgments while attempting to cross a street. [4]

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Pedestrian and driver traffic control violations generally receive low levels of enforcement.

Intersection reconstruction projects and traffic control installations can increase the distance that one must walk to cross at an intersection. Intersection signal timings may be too short to permit safe intersection crossing. Assumptions of walking speeds for signal timing may be too fast for many pedestrians to cross to the other side of the curb. Also, there appears to be a poor understanding of pedestrian signal displays by pedestrians.

Crash data consistently show that crashes with pedestrians occur far more often with turning vehicles than with straight-through traffic. Left-turning vehicles are more often involved in pedestrian collisions than right-turning vehicles, partly because drivers are not clearly able to see pedestrians on the left. [5]

Right-turn-on-red (RTOR) can potentially contribute to pedestrian crashes because it creates conflicts between pedestrians and motor vehicles and can reduce pedestrian opportunities to cross intersections, even though pedestrians have the right-of-way over the right-turning vehicles.

Pedestrian visibility to drivers is worse during hours of darkness, especially in areas where there is poor lighting on the road. This is a common shortcoming of rural and suburban intersections. Studies of pedestrian and driver reactions indicate that pedestrians generally perceive that they are visible to drivers before they are visible.

Pedestrian Safety Countermeasures

The following section provides possible pedestrian safety countermeasures within the following categories: crosswalk improvements, intersection design/physical improvements, intersection operations and signal hardware/technology. Modifications to pedestrian control devices from the *2003 Manual on Uniform Traffic Control Devices* (MUTCD) are also included.

Crosswalk Improvements

- Use a ladder or cross-hatched pattern that is more visible to motorists;
- Use "Pedestrian Crossing" warning signs with pedestrian-actuated flashing beacons, which alert oncoming traffic to pedestrians in the crosswalk;
- Move the vehicle STOP line farther back from crosswalk AND add STOP HERE FOR PEDESTRIANS sign;
- Install raised crosswalks;
- Sign and mark crosswalks. For greatest effectiveness, include curb ramps or curb extensions;
- Use in-pavement lights to alert motorists to the presence of a pedestrian crossing or when someone is preparing to cross the street. Transportation professionals should review the new Chapter 4L of the 2003 MUTCD that provides guidance on the use of in-pavement lights at crosswalks;
- Consider using MUTCD Sign R1-6: STOP FOR PEDESTRIANS or YIELD TO PEDESTRIANS signs can be placed at crosswalks without signals in central business districts and other areas of high pedestrian activity to reinforce and remind drivers of the laws regarding the right-of-way of pedestrians; and
- MUTCD Sign R1-5(a): YIELD HERE TO PEDESTRIANS signs are for use in advance of unsignalized marked mid-block crosswalks.

R1-6

R1-5(a)

Safety Effects Of Marked Vs. Unmarked Crosswalks At Uncontrolled Locations [6]

- **On two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk.**
- **On multi-lane roads with traffic volumes of more than 12,000 vehicles per day, having a marked crosswalk was associated with a higher pedestrian crash rate compared to an unmarked crosswalk.**
- **Raised medians provided significantly lower pedestrian crash rates on multi-lane roads, compared to roads with no raised median.**

Intersection Design/ Physical Improvements

- Install barriers such as fences or shrubs to discourage pedestrians from crossing at unsafe locations;
- Install bulb-outs at intersections to reduce pedestrian crossing distance;
- Provide wide refuge islands and medians;
- Construct pedestrian overpasses/underpasses;
- Install raised medians; and
- Reduce corner radii.

Intersection Operations

- Reassess traffic signal operations, including consideration of pedestrian walking speeds/pedestrian signal timing and pedestrian-only phasing Consider restricting right-turn-on-red (RTOR);
- Illumination;
- Mid-block traffic signal; and
- Far-side bus stops.

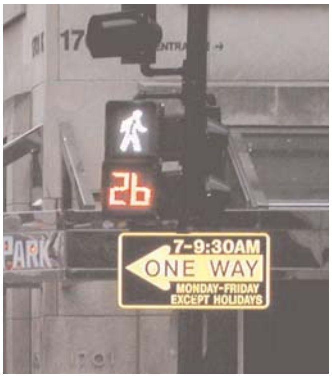
Signal Hardware/ Technology

Consider installation of Pedestrian Countdown Signals

2003 MUTCD Section 4E.07 Countdown Pedestrian Signals
A pedestrian interval countdown display may be added to a pedestrian signal head in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.

Consider installation of Animated Eye Pedestrian Signal

Animated eyes are intended for use at pedestrian crosswalks as an alternative to conventional pedestrian signals. Animated eye displays may encourage pedestrians to look for turning vehicles traveling on an intersecting path by including a prompt as part of the pedestrian signal. The prompt is a pair of animated eyes that scan from side to side at the start of the WALK indication.



Accessible Pedestrian Signals

2003 MUTCD: Section 4E.06 Accessible Pedestrian Signals (APS)
The installation of APS at signalized locations should be based on an engineering study, which should consider the following factors: **(1)** potential demand for accessible pedestrian signals; **(2)** a request for accessible pedestrian signals; **(3)** traffic volumes during times when pedestrians might be present, including periods of low-traffic volumes or high turn-on-red volumes; **(4)** complexity of traffic signal phasing; and **(5)** complexity of intersection geometry. When using APS, the pedestrian signal must be visible and any push-buttons must be accessible with audible locator tones for people with visual disabilities.

Pedestrian Intervals and Signal Phases

2003 MUTCD Section 4E.10
The pedestrian clearance time should be sufficient enough to allow a crossing pedestrian, who left the curb or shoulder during the WALKING PERSON signal indication, to travel at a walking speed of 4 ft. per second to make it **to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.** Where pedestrians, who walk slower than 4 ft. per second or use wheelchairs, routinely use the crosswalk, a walking speed of less than 4 ft. per second should be considered in determining the pedestrian clearance time.

The Three E-Approach: Engineering Alone is Not Sufficient

Improved pedestrian safety at intersections requires coordination among public authorities, professional engineers, media, education experts and vehicle designers to reduce both the number and severity of pedestrian collisions. Pedestrian safety cannot be improved by traffic engineering alone; it is a partnership between the driver, pedestrians, parents of young children, schools, police departments and others.

From an enforcement perspective, we need to ensure motorist compliance with traffic control devices, posted speeds and pedestrian safety laws. Pedestrians need to understand and obey intersection traffic control. Pedestrians need to make themselves more visible during evening and nighttime hours. One way to do this is to wear reflective clothing and accessories. All partners need to develop a sustained and comprehensive intersection safety public awareness campaign that reaches both motorists and pedestrians.

Sample Pedestrian Safety Programs/Tools

Federal Highway Administration's Pedestrian Safety Campaign Planner

This toolkit contains outreach materials that states and local jurisdictions and communities can customize and

use locally. The threefold purpose of the campaign is to **(1)** sensitize drivers to the fact that pedestrians are legitimate road users and should always be expected on or near the roadway, **(2)** educate pedestrians about minimizing risks to their safety and **(3)** develop program materials to explain or enhance the operation of pedestrian facilities, such as crosswalks and pedestrian signals.
http://safety.fhwa.dot.gov/pedcampaign/index.htm

Federal Highway Administration's Crash Group/General Countermeasure Matrix

This tool identifies potential solutions for use by safety practitioners. This matrix is particularly helpful as a resource of potential engineering countermeasures, which may be implemented at a location to address a particular pedestrian crash type.
http://safety.fhwa.dot.gov/saferjourney/Library/matrix.htm

Federal Highway Administration's Pedestrian and Bicycle Crash Analysis Tool (PBCAT)

The Pedestrian and Bicycle Crash Analysis Tool is a crash-typing software intended to assist state and local pedestrian/bicycle coordinators, planners and engineers with improving walking and bicycling safety through the development and analysis of a database containing details associated with crashes between motor vehicles and pedestrians or bicyclists. The software allows a person to:

- Determine the *crash type* through a series of on-screen questions about the crash, crash location and maneuvers of the parties involved;
- Customize the database in terms of units of measurement, variables and location referencing, as well as import/export data from/to other databases;
- Produce a series of tables and graphs defining the various crash types and other factors associated with the crashes, such as age, gender and light conditions; and
- Recommend countermeasures linked to specific bicycle and pedestrian crash types and related resource and reference information.

This tool can be ordered free of charge through the following Web site.
http://www.walkinginfo.org/pc/order. htm.

ITE/Partnership for A Walkable America

Pedestrian Project Awards

ITE, in cooperation with the Partnership for a Walkable America and a grant from the Robert Wood Johnson Foundation, conducted a Pedestrian Project Award Program in 2003. More than 106 submittals were received in six categories: safety, facilities, education, policy, partnerships and elderly and mobility impaired. Each submission, including the program description for both the winners and all nominees, has been digitized and is included on ITE's Transportation and Active Living Web Site as follows:
http://www.ite.org/activeliving/index.asp.

The 2003 Pedestrian Awards were given to the following organizations:

- **Safety.** City of Boulder Colorado and Short Elliott Hendrickson
- **Facilities.** New York Department of Transportation and Vollmer Associates LLP.
- **Education.** Utah Department of Health and the Utah Highway Safety Office for the Green Ribbon Month project.
- **Policies.** The Wisconsin Department of Transportation for the Wisconsin Pedestrian Policy Plan 2020.
- **Partnership.** City Council Member Richard Conlin and Feet First for Seattle's Pedestrian Summer project.
- **Elderly and Mobility Impaired.** City of Portland, et. al.

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Additional Resources

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http://www.walkinginfo.org/

U.S. Access Board.
http://www.access-board.gov/

Walkinginfo.org Accessible Pedestrian Signals Home Page.
http://www.walkinginfo.org/aps/home.cfm

10 ISSUE BRIEFS

Older Drivers at Intersections

The Problem

Driving within intersection environments requires complex speed-distance judgments under time constraints. This scenario for intersection operations can be more problematic for older drivers and pedestrians than for their younger counterparts. For the calendar period from 1997 to 2002, fatalities at intersections for drivers aged 65 and older ranged from 2,500 to 2,950 each year.

According to the National Highway Traffic Safety Administration, older drivers are more likely than drivers in their 30s, 40s, or 50s to be involved in traffic crashes, and they are more likely to be killed in traffic crashes. The number of Americans 65 years of age and older is expected to double between 2000 and 2030. Americans are living longer and driving longer. Together these trends suggest that the number of older drivers killed on U.S. streets and highways will grow. [1]

The AAA Foundation for Traffic Safety recently released a report entitled, "Older Driver Involvement in Injury Crashes in Texas: 1975 to 1999." This study evaluated 25 years of police-level crash data from nearly 4 million injury crashes in the state of Texas. Crashes were analyzed to determine the association between driver age and four factors: fragility—the likelihood of death among drivers involved in injury crashes; illness—the likelihood that drivers were ill or suffering from some other physical defect at the time of their crashes; perceptual lapses—the likelihood that drivers involved in crashes failed to yield the right-of-way or disregarded traffic signs or signals and left turns—the likelihood that left turns were involved in injury crashes. Readers are encouraged to review the entire research report which is available in PDF on the AAA Foundation Web site.

Three different age thresholds were used in defining the older population. Group 1, persons are 65 years of age and older; Group 2, persons 75 and older; and Group 3, persons 85 and older. Drivers aged 55 to 64 constituted the comparison group in the analyses. When the analyses controlled for crash type (single-vehicle vs. multiple vehicle), population density (rural vs. urban), driver sex (male vs. female), light condition (daylight vs. darkness) and intersection relatedness, drivers in the three older age categories, compared with drivers aged 55–64, were found to be more likely to die in injury crashes:

- Drivers 65+ years of age were 1.78 times as likely to die;
- Drivers 75+ years of age were 2.59 times as likely to die; and
- Drivers 85+ years of age were 3.72 times as likely to die.

In addition, all three older person groups were more likely to (1) have been ill or suffering some other physical defect at the time of their crashes, (2) have suffered perceptual lapses that contributed to their crashes (such as failure to yield the right-of-way or disregarding signs or signals) and (3) have been involved in left-turn crashes.

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Figure 1 shows a comparison of total fatalities to intersection fatalities for the years 2000 through 2002 for three age groups: 64 and younger, ages 65 to 74 and for ages 75 and older. As shown, when considering total fatalities, the percentage of intersection fatalities involving older people in both the 65 to 74 and 75 and older age groups are clearly overrepresented.

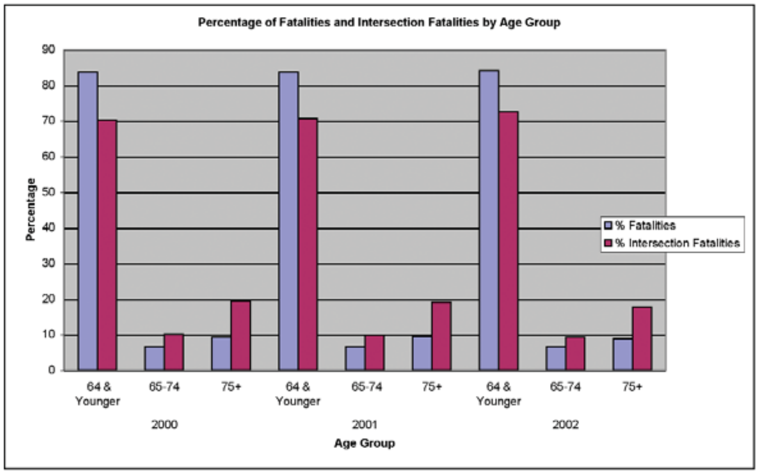

Figure 1

Source: Fatal Analysis Reporting System (FARS). 2000, 2001, and 2002.

Project Planning Considerations

During the planning stage for each project involving new construction or reconstruction of an existing intersection, practitioners should seek answers to the following four questions:

- Is there a demonstrated crash problem with older drivers or pedestrians?
- Has any aspect of design or operations at the project location been associated with complaints to local or state officials from older road users or are you aware of a potential safety problem, either through personal observation or agency documentation, applying your own engineering judgment?
- Is this project located on a direct link to a travel origin or destination for which older people constitute a significant proportion of current users?
- Is the project located in an area experiencing an increase in the proportion of residents aged 65 and older?
- Is this project located on a direct link to a travel origin or destination for which older people constitute a significant proportion of current users?
- Is this project located in an area that will constitute a significant proportion of *future* older people, perhaps where there is a planned medical center or senior housing project nearby?

Engineering Solutions To Make Intersections Safer for Older Drivers

The solutions to reduce older driver crashes incorporated into this briefing sheet have been extracted from the *FHWA Older Driver Design Handbook*. These solutions should benefit all road users, not just older people. It is acknowledged that intersection projects may have constraints, such as high construction costs, the need for additional right-of-way, local access management requirements, sight distance and other issues that may preclude the use of the suggested solutions. In all cases, professional engineering judgement must be used to validate the use or non-use of a particular solution set.

Design

- Use a minimum receiving lane width of 12 ft. accompanied, wherever practical, by a minimum 4-ft. shoulder;
- Use positive offset of opposing left-turn lanes to increase the safety for older drivers who, as a group, do not position themselves within the intersection before initiating a left turn;
- In the design of new facilities or redesign of existing facilities where right-of-way is not restricted, all intersecting roadways should meet at a 90-degree angle. Where right-of-way restrictions are present, intersecting roadways should meet at an angle of no less than 75 degrees;
- Where roadways intersect at 90 degrees and are joined with a simple radius curve, provide a corner curb radius in the range of 25 ft. to 30 ft. to: **(a)** facilitate vehicle turning movements, **(b)** moderate the speed of turning vehicles, and **(c)** avoid unnecessary lengthening of pedestrian crossing distances; and
- For left- and right-turn lane treatments, provide raised channelization with sloping curbed medians.

Signs

- Install larger (oversized) regulatory and warning signs;
- Use signs fabricated using high intensity retroreflective sheeting;
- Use redundant street-name signing for major intersections with an advance street-name sign placed upstream of the intersection at a midblock location;
- Increase sign lettering size for street names, directional signing and advance intersection signing;
- Install more overhead-lighted advance signing prior to major intersections. Include overhead lane-use control signs to help driv-

ers get into the proper lane in advance of the intersection;

- Use overhead-mounted street-name signs as a supplement to post-mounted street-name signs;
- When using advance intersection warning signs, accompany the signs with an advance street-name plaque;
- When different street names are used for different directions of travel on a crossroad, the names should be separated and accompanied by directional arrows on both advance midblock and intersection street-name signs;
- Where appropriate (e.g. dual-turn lanes or where a through lane becomes a turn-only lane) use lane-use control signs at intersections on a signal mast arm or span wire;
- Where appropriate, use the **LEFT TURN YIELD ON GREEN ●** with protected-permitted mode left-turn signal phases;
- Where practical, use a redundant upstream **LEFT TURN YIELD ON GREEN ●** sign at the start of the left-turn lane, in addition to using the same sign adjacent to the signal face, to remind left-turning drivers of the requirement to yield to oncoming traffic before turning on green.

Pavement Markings

- Treat the median and island curb-sides and curb horizontal surfaces with retro-reflectorized markings and maintain them at a minimum luminance contrast level;
- Provide more visible and durable pavement markings;
- Use retroreflective raised pavement markings;
- Use wider pavement markings;
- Use transverse pavement striping or rumble strips upstream of stop-controlled intersections where there may be sight restrictions, high approach speeds, or a history of ran-stop-sign crashes. This treatment can also be used in rural areas where a stop sign is encountered after a long distance with no traffic control devices;
- Delineate median noses using retroreflective treatments to increase visibility and improve driver understanding; and
- Where appropriate (e.g. for exclusive left- or right-turn lanes) use lane-use arrow pavement markings at appropriate distances in advance of a signalized intersection.

Traffic Signal Operations

- Where minimum sight-distances cannot be achieved or where a pattern of permitted left-turn crashes occurs, eliminate permitted left turns and use protected-only left-turn operations;
- Consider the use of a separate signal face to control turning phase versus through movements;
- Use a leading protected left-turn phase wherever protected left-turn signal operation is implemented as opposed to a lagging protected left-turn phase;
- Consider the use of a leading protected left-turn phase wherever protected-only left-turn signal operation is implemented as opposed to a lagging protected left-turn phase. Lagging left-turn operations, however, are more beneficial for reducing vehicular/older pedestrian conflicts since the pedestrian crossing is normally completed before the beginning of the lag-left green arrow display;
- Use of red left arrows instead of a circular red indication at left turn signals;
- To accommodate age differences in perception-reaction time, use the yellow change interval and all-red clearance interval formulae in the Institute of Transportation Engineers' publication entitled, *Traffic Engineering Handbook, Fifth Edition*; and
- Assume slower walking speeds for signal-clearance timing in the range of 3.5 feet per second if actual crossing times are not available. Time the clearance interval for a full crossing, or to a median, but not just to the middle of the farthest lane.

Traffic Signal Hardware

- Install larger (12 in.) signal lenses;
- Consistently use backplates with traffic signals on all roads with operating speeds of 40 mph or higher. The use of backplates with signals on roads with operating speeds lower than 40 mph should be used where there may be special factors such as sun glare, a potential for wrong-way movements and high nighttime pedestrian volumes;
- Conduct regular cleaning of lamp lenses and replace lamps when output has degraded by 20 percent or more from peak performance for all fixed lighting installations at intersections;
- Install additional signal heads;
- Install more overhead traffic signals; and
- Consider using post-mounted signals (sometimes called "secondary," "low level" and "far-side left signal heads") to accommodate left-turn drivers waiting in the intersection to turn (permissive-only). Older drivers sometimes cannot easily view an overhead signal (which is usually to their right) at the same time they are looking for gaps in opposing traffic, especially if the overhead signals are strung on a diagonal span wire.

Right-Turns-on-Red (RTOR)

- Where a RTOR is prohibited, use more than one **NO TURN ON RED** sign. A supplemental **NO TURN ON RED** sign should be placed on the overhead mast arm and at a location on either the near or opposite side of the intersection where it will be most conspicuous; and

- At skewed intersections where the approach leg to the left intersects the driver's approach leg at an angle of less than 75 degrees, prohibit RTOR.

Resources

FHWA. *Older Driver Highway Design Handbook.* January 1998. FHWA. Publication FHWA-RD-97-135.
http://ntl.bts.gov/DOCS/older/home/index.html

Griffin, Lindsay F. III. *Older Driver Involvement in Injury Crashes in Texas: 1995-1999.* AAA Foundation for Traffic Safety, February 2004.
http://www.aaafoundation.org.pdf/OlderDriverInvolvementInInjuryCrashes.pdf

ITE Traffic Engineering Handbook, 5th Edition. 1999.

MUTCD: **http://mutcd.fhwa.dot.gov.**

Pedestrian Design for Accessibility Within the Public Right-of-Way

Introduction

The design and operation of intersections often fail to include features for good pedestrian access and safety, including consideration of people with visual and mobility disabilities. The pedestrian system must be usable for pedestrians of all ages and capabilities and must provide safe crossing intersections for older people and young children.

The pedestrian system has traditionally been designed for people who are mentally and physically agile, with good stamina, vision and hearing. However, 20 percent of the U.S. population has a disability and 70 percent of the population will have a permanent or temporary disability in time.

The Americans with Disabilities Act (ADA) has minimum design standards that are to be applied to all public environments and this includes the public right-of-way. These standards, the Americans with Disabilities Act Accessibility Guidelines (ADAAG), are the foundation for designing all pedestrian environments, and better design practices are encouraged to be applied whenever possible. Pedestrian accessibility enhancements will not only benefit people with disabilities; they will benefit able-bodied pedestrians as well. Examples include curb ramp improvements that will assist people pushing carts or strollers and placing the WALK push buttons in a place that is accessible and easily understandable for all intersection users.

Entities are encouraged to design and set codes beyond the minimum standards to facilitate access for a wider spectrum of people—they may not design below the standards. An entity is still responsible for making the features/facility accessible if a specific standard has not been adopted for that feature/facility. The nondiscrimination requirements for usability by people with disabilities in ADA are the overarching regulations that must be applied. It is critical for transportation providers to understand the details and principals for accessible design in order to apply good engineering judgment in difficult design situations. Pedestrian facilities with physical barriers, unusable sign and signal information, gaps in the system and poorly designed features have critical safety implications for people with disabilities and may leave them stranded and unable to get to their destinations.

Challenges for Engineers and Designers

For pedestrians with disabilities, intersections prove a special challenge:

- Often the walking speed (generally set at 4 ft. per second) used for timing clearance phases is not sufficient for people who are elderly or have disabilities, leaving them stranded in the intersection when the traffic signal changes;
- At intersections, turning vehicles and the speed at which they travel pose the greatest threat to pedestrians, and often the motorist's attention is focused on other motorists; and

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- Right-turn-on-red, roundabouts and channelized right-turn lanes and other features designed to move traffic more quickly can be hazardous for people with visual disabilities, who rely on the sounds of traffic stopping and surging to judge adequate gaps in traffic and WALK phases. The surging and stopping cues at traditional intersections are not present at many of the intersection designs that have been installed during the past two to three decades, and if unable to reasonably judge crossing gaps, it is nearly impossible for people with visual disabilities to cross the street with an assured amount of safety.

Questions to Ask During Project Development

Designing for accessibility is largely a matter of common sense on the part of the designer or engineer, once there is awareness and understanding. It means understanding the capabilities of users (children, elderly, people with cognitive, visual and mobility disabilities) and knowing how a facility should perform for all pedestrians.

Some of the questions to ask are:

- Are the sidewalks passable by people using wheelchairs, walkers and strollers?
- Are crosswalks accessible?
- Are there curb ramps (two per corner where practical)?
- Do the ramps comply with ADA specifications (critical design aspects are the presence of a level platform at the top of the ramp, cross-slope of the ramp and wheelchair traps at the base of the ramp)?
- Is the ramp located in the path pedestrian travel (i.e., do people wanting to use the ramp need to divert from the most direct path)?
- Is the push button of an actuated pedestrian traffic signal accessible?
- Does it have a locator tone for people who are blind?
- Is the button proximate to the crosswalk?
- Is it clear which crosswalk the button actuates?
- Is the button located within reach of a wheelchair user or child?
- Are there non-visual cues that alert pedestrians to when they are leaving the sidewalk and entering the street (examples are curb, lip of an ADA ramp, or other tactile surface)?
- Is there an alternate route for pedestrians at construction sites?
- Are there cues at the site giving a person using a white cane the information that is needed to know there is a sidewalk closure or open pit?
- Does the information give cues on how to navigate safely around the site and not into the construction?
- Is there a wheelchair ramp at the site for users to navigate to the alternate route?
- Can pedestrians (especially a person with low vision) see the pedestrian signal across the street?
- Is the pedestrian signal located on the same pole as the vehicle indication for conflicting movements (normally left and right turns) so that pedestrians understand vehicle conflicts and visa versa?
- Is the pedestrian signal located on the inside edge of the crosswalk so that a truck stopped at the intersection will not obstruct it?
- Are pedestrian signs easy to understand and interpret?
- Are there design features that create special challenges for visually impaired pedestrians (examples: right-turns-on-red, right-slip lanes, or roundabouts without controlled crossings)?

References

For more information on the safe accommodation of pedestrians with disabilities, refer to the following publications and Web sites for resources:

1. Accessible Design for the Blind. Research, guidance and instructional materials on the use of Accessible Pedestrian Signals (APS) and detectable warnings, http://www.accessforblind.org

2. Barlow, Janet M., Billie Louise and Lee S. Tabor, AIA. *NCHRP 3-62: Accessible Pedestrian Signals: Synthesis and Guide to Best Practices, Final Report. May 2003.* http://www.walkinginfo.org/aps/pdf/APS-Synthesis.pdf

3. Barlow, Janet, Pat Cannon, Dan Dawson, et. al. *Building a True Community: Final Report:* Public Rights-of-Way Access Advisory Committee, for the U.S. Access Board, February 2001. http://www.access-board.gov

4. Bentzen, Billie Louise and Lee S. Tabor, AIA. *Accessible Pedestrian Signals.* Work performed in support of the U.S. Access Board under Contract No.PD-97-0772, August 1998. http://www.access-board.gov/research&training/pedsignals/pedestrian.htm

5. Bentzen, Billie Louise PhD, Janet M. Barlow, COMS and Lee S. Tabor. *Detectable Warnings: Synthesis Of U.S. And International Practice. May 2000.* http://www.access-board.gov/publications/DW%20Synthesis/report.htm

6. *FHWA. Designing Sidewalks and Trails for Access: Best Practices Guide Part II of II.* http://www.fhwa.dot.gov/environment/sidewalk2/index.htm

7. *FHWA. Manual on Uniform Traffic Control Devices* (MUTCD) provides the standards for traffic control devices and included information on Accessible Pedestrian Signals (APS), Chapter 4E and Temporary Traffic Control Elements, Chapter 6D, http://mutcd.fhwa.dot.gov

8. ITE. *Traffic Control Device Handbook*. Washington, DC: ITE, 2001. Pedestrians, Chapter 13.

9. Noyce, David A. Ph.D., P.E. and Janet M. Barlow, C.O.M.S. *Interfacing Accessible Pedestrian Signals and Traffic Signal Controllers.* April 2003. http://www.access-board.gov/research&training/APS/report.htm

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Human Factors Issues in Intersection Safety

Research indicates that driver error may account for approximately 90 percent of all crashes. While advances in automotive safety and highway design continue to improve, the one component that has not changed is the driver. Understanding how drivers and all roadway users interact within an intersection environment is fundamental to improve roadway safety and save lives.

Driver Attention and Decision-Making

Negotiating intersections is one of the most complex and demanding tasks a driver faces. To successfully execute a vehicle maneuver through an intersection, the driver must assimilate the information, make a decision and execute the desired action. One limitation is that humans are serial processors and the cognitive task-load at intersections can be quite large. Common items a driver must consider when approaching an intersection include:

- Monitoring and adjusting speed;
- Maintaining lane position;
- Being aware of other vehicles;
- Attending to signals or signs;
- Scanning for pedestrians, bicyclists, people in wheelchairs and blind or visually-impaired people;
- Decelerating for a stop;
- Searching for path guidance; and
- Selecting proper lane.

Given the short time drivers have to process a large amount of information, it is imperative that designers and engineers provide clear and accurate information to drivers to help them navigate an intersection.

Vision is the most important information reception characteristic of drivers. Features of human vision are tied to specific roadway design elements as illustrated in Table 1.

Table 1: Human Vision Characteristics as Related to Roadway Elements

Visual Characteristic	Related Roadway Element(s)
Visual Acuity. Ability to see small details clearly.	Sign size; reading distant traffic signs
Contrast Sensitivity. Seeing objects that are similar in brightness to their background.	Pavement markings and delineation; detection of dark clothed pedestrians at night
Color Vision. Discrimination of different colors.	Sign and signal design and retroreflectivity
Visual Field/Peripheral Vision	Sign placement, signal placement; seeing a bicycle approaching from the left
Scan Patterns	Sign placement, delineation treatments
Motion Judgment/Angular Movement. Seeing objects moving across the field of view.	School zones, highway railroad crossings; Judging the speed of cars crossing our path of travel
Movement in Depth. Detecting changes in visual image size.	Judging the speed of an approaching vehicle
Visual Illusions	Guide signs, pavement markings
Depth Perception. Judgment of the distance of objects.	Passing on two-lane roads with oncoming traffic
Eye Movement. Changing the direction of gaze.	Scanning the road environment for hazards
Glare Sensitivity. Ability to resist and recover from the effects of glare	Reduction in visual performance due to headlight glare

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Driver Error

Perceptual failures account for a large portion of driver errors. These can include such items as "looked but failed to see," visual obstructions, reduced visibility due to environmental factors, poor judgment of speed and/or distance and low conspicuity of target. However distraction, misinterpretation of information and driver impairment are also major contributing factors. Intersections themselves present their own unique set of driver errors, depending on the type of intersection at hand.

Signalized Intersections

Common driver errors include:

- Not understanding whether to proceed or stop at a yellow-signal indication (e.g. This is known as the dilemma zone);
- Underestimating time to reach an intersection;
- Underestimating time to make a smooth stop;
- Failure to detect signal and proper lane assignment; and
- Misinterpreting guide sign information.

Unsignalized Intersections

Common driver errors include:

- Unsafe gap acceptance;
- Inaccurate estimation of approaching vehicles' speed;
- Underestimating time to accelerate after making a turn; and
- Failure to yield right-of-way.

Design Considerations

Design policy implicitly incorporates principles of human factors. The "design driver" is assumed by American Association of State Highway Transportation Officials (AASHTO) to be alert and in control of physical and mental abilities; to have a reasonable ability to see and perceive the roadway environment; and to have reasonable motor skills to enable steering, braking and other operations. Table 2 summarizes key human factor considerations and their relationship to design elements.

Table 2: Human Factors and Their Relationship to Roadway Design Elements

Human Factor	Design Value	Design Element Affected
Perception-reaction time	1.0-2.5 sec.	Stopping Sight Distance
Deceleration rate	11.2ft./sec.^{2}	Stopping Sight Distance
Pre-maneuver. Distance for driver to detect an unexpected condition.	3.0-9.1 sec.	Decision Sight Distances
Gap acceptance Turning left or right from stop Crossing from stop	7.5 sec. Minimum 6.5 sec. Minimum	Stopping Sight Distance Stopping Sight Distance
Driver height of eye	1080 mm	Stopping Sight Distance
Pedestrian walk times	3.0-4.5 fps	Pedestrian Facilities

Engineering Solutions

Humans are not perfect when making decisions, and some errors in judgment are inevitable. However, steps can be taken to help reduce the likelihood that driver errors will take place. Therefore, intersection design and features are important and should take the limitations of human performance into account.

A signification proportion of intersection crashes involve left-turn maneuvers. Older drivers in particular run the greatest risk of being involved in a left-turn accident, due in part to their diminished ability to judge closure rates of oncoming vehicles. Using alternative intersection designs for left-turn lanes can help alleviate this problem. For example, a positive offset design can help improve visibility of oncoming vehicles. Adding protected left-turn phases can also assist drivers in turning movements.

Other elements of the intersection can be added or modified to improve driver performance and reduce the likelihood of errors. Some include:

- Using advanced guide signs that are placed in conspicuous locations;
- Using large pavement markings and scribing path markings for multiple turn lanes;
- Using larger 12 in. signals or beacons;
- Using pedestrian refuge islands when possible;
- Reducing size of dilemma zone with appropriate amber-phase timing or advanced detection;

- Ensuring that the intersection is free of visual obstructions;
- Avoiding permissive right-turn-on-red when intersection skew angle is less than 75 degrees; and
- Ensuring crosswalks are easily visible with high visibility markings and/or beacons.

Training

National Highway Institute Course:

Human Factors for Transportation Engineers

For further information, contact FHWA, Office of Safety, at 202-366-8156.

This one-day workshop includes interactive modules on information reception, decision-making, driver responses and human factors principles. Upon completion of the course, participants will be able to:

- Recognize that human factors have a role in highway design, operations and safety decisions;
- Describe human factors information that is included in today's guidelines and standards;
- Identify human capabilities needed for using roadways; and
- Apply basic human factors principles to resolve issues related to highway design, operations and safety.

Resources

1. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets, Fourth Edition*. Washington, DC: AASHTO, 2001.

2. Institute of Transportation Engineers. *Traffic Engineering Handbook, 5th Edition*. Washington, DC: ITE, 1999.

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ISSUE BRIEF

Access Management

Access Management: A Key to Safety and Mobility

Access management can be defined as the process or development of a program intended to ensure that the major arterials, intersections and freeway systems serving a community or region will operate safely and efficiently while adequately meeting the access needs of the abutting land uses along the roadway. The use of access management techniques is designed to increase roadway capacity, manage congestion and reduce crashes.

Through the years, extensive investment for public roadway infrastructure has been made. This has largely involved public funds, but private monies also have contributed to rebuilding and enhancing the street system. During the past 30 years or more, the ability to increase roadway capacity has been increasingly difficult due to both economic and environmental constraints. Areas that do not practice effective access management face more rapid deterioration of the quality of traffic flow than those areas with a well-thought out access management policy in place.

The purpose of this briefing sheet is to describe the traffic engineering and design considerations in relation to the use of access management techniques to increase safety and reduce crashes.

The lack of an access management plan or policy will ultimately result in a number of negative consequences including:

- Reduction in overall safety reflected by the increase in crashes;
- Greater number of conflicts and potential hazards between vehicular bicycle and pedestrian movements;
- Diversion of through traffic into abutting neighborhoods in attempt to bypass added congestion;
- Increased congestion with slower travel speeds and delays to arterial traffic; and
- Non-transportation effects such as increase in strip commercial development, less pleasing visual settings and ultimately, a poor image for the businesses along the corridor.

Traffic Engineering and Design Considerations to Enhance Access Management

Some of the most significant areas to address in relation to access management are related to *traffic signal spacing, the number of driveways* and the *characteristics of an intersection.*

Traffic Signal Spacing

Figure 1 shows comparative accident rates for a given signal density and number of unsignalized access points per mile. The graph clearly shows that a greater number of access points and signals per mile translate into increases in crash rates. As an example, if the number of access points are held constant at less

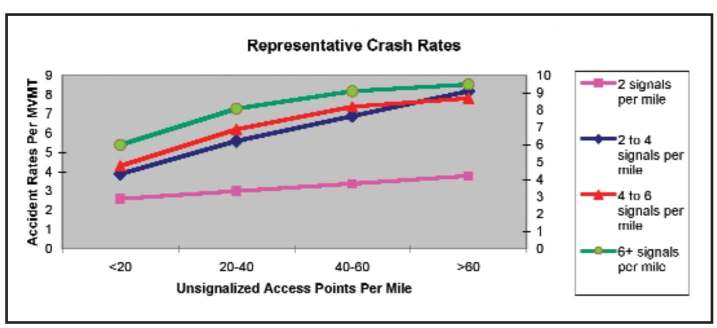

Figure 1

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than 20 unsignalized access points per mile, and the number of signals per mile are categorized as less than two, as compared to two to four signals per mile, there is a 50 percent increase in the crash rate (from 2.6 million vehicle miles of travel (mvmt) to 3.9 mvmt.

Table 1 considers the number of signals per mile in comparison to crash data compiled from seven states. As shown, there is an increase in the crash rate of 158 percent (from 3.53 crashes per mvmt to 9.11 crashes per mvmt) when under conditions of less than two signals per mile as compared to six or more signals per mile.

Table 1

Signal Per Mile	Crashes Per MVMT
Under 2	3.53
2 to 4	6.89
4 to 6	7.49
6+	9.11

Intersection Spacing

As the number of intersections per mile increases, the opportunity for crashes increase. The existence of too many intersections per mile also increases delay and congestion. Table 2 provides a few rules of thumb for intersection spacing:

Table 2

Intersection Spacing/ Roadway Types	Suggested Spacing
Arterial (major roadway) to arterial (intersecting minor roadway)	≥ 1 mile
Arterial (major roadway) to collector (intersecting minor roadway)	≥ 0.5 mile
Intersection of local roads with arterials is not recommended; However if required	500 to 660 feet
Rural areas, intersections between public roads	0.5 mile; preferred 1 mile

The Iowa Department of Transportation conducted an access management research project and collected data in seven communities in conjunction with the development of an access management awareness program. Figure 2 shows the number and type of accidents

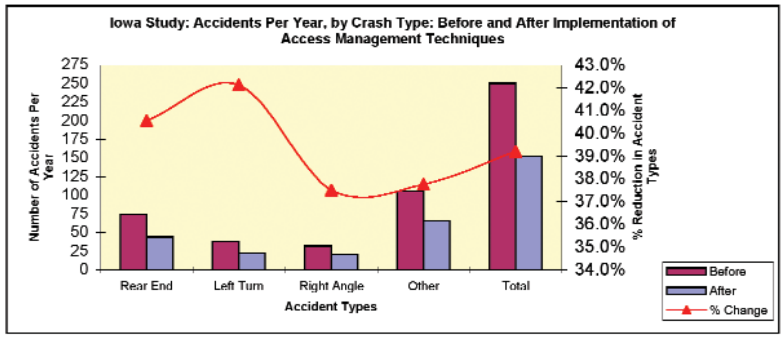

Figure 2

per year (and percentage reduction) prior to and after implementation of a series of access management techniques. As shown, total accidents were reduced by approximately 39 percent; and rear-end and left-turn accidents were reduced by 41 and 42 percent, respectively.

Functional Areas of Intersections

The functional area of an intersection is that area beyond the physical intersection of two roadways that comprises decision and maneuvering distance, plus any required vehicle storage length. The functional area includes the length of road upstream from an oncoming intersection needed by motorists to perceive the intersection and begin maneuvers to negotiate it.

The upstream area consists of distance for travel during a perception-reaction time, travel for maneuvering and deceleration and queue storage. The functional area includes the length of road downstream from the intersection needed to reduce conflicts between through traffic and vehicles entering and exiting a property.

Driveways should not be located within the functional area of an intersection.

Driveways located within the functional area may create too many conflict points within too small an area for motorists to safety negotiate.

The integrity of functional areas of intersections can be protected through corner clearance, driveway spacing and intersection spacing requirements. Intersections should be spaced far enough apart so that functional areas do not overlap.

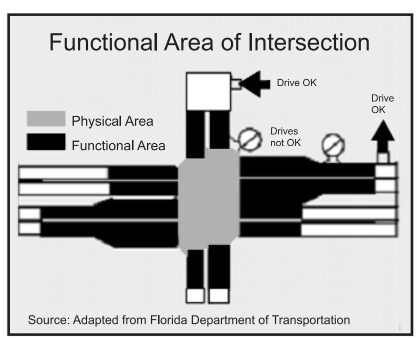

Figure 3

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Access Management Tools and Techniques

There are a number of other tools and techniques available to consider for use as part of an access management plan. They include both physical design techniques as well as policy related addressing land development and roadway design standards. Examples of common and highly effective techniques are:

- ✦ Consolidate and minimize left turn exits from driveways;
- ✦ Use a two-way center left-turn lane;
- ✦ Use of raised center median;
- ✦ Encourage shared driveways for adjacent land parcels/developments;
- ✦ Create service roads for direct land access parallel to major arterial; and
- ✦ Provision of adequately designed turn lanes.

Resources

1. American Association of State Highway Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. Washington, DC: AASHTO, 2001.

2. Center for Transportation Research and Education. *Intersection Spacing and Traffic Signal Spacing*, Access Management Frequently Asked Questions 4; http://www.ctre.iastate.edu/Research/access/toolkit/4.pdf

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7. FHWA. *Benefits of Access Management*, FHWA Document FHWA-OP-03-066.

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9. Iowa Department of Transportation and the Iowa Highway Research Board. *Access Management Awareness Program, Phase II Report*, the Iowa DOT Project TR-402 CTRE Management Project 97-1. Center for Transportation Research and Education CTRE, December 1997.

10. Parsonson, P.S. M. Walters, and J. S. Fincher. *Effect on Safety of Replacing an Arterial Continuous Two-Way Left-Turn Lane with a Raised Median*. 1st National Conference on Access Management. Vail, CO, 1993.

11. Parsonson, P.S. M. Walters, and J. S. Fincher. *Georgia Study Confirms the Continuing Safety Advantage of Raised Medians over Continuous Two-Way Left-Turn Lanes*. 4th National Conference on Access Management. Portland, OR, 2000.

12. S & K Transportation Consultants. Inc. *Access Management, Location and Design*, Participant Notebook for NHI Course 133078. National Highway Institute, April 2000.

13. Transportation Research Board. *Access Management Manual*.

14. Transportation Research Board. *NCHRP 348, Access Management Guidelines for Activity Centers*. Washington, DC: TRB, 1992.

15. Transportation Research Board. *NCHRP 420, Impacts of Access Management Techniques*. Washington, DC: TRB, 1999.

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Roundabouts

A proven safety solution that reduces the number and severity of intersection crashes.

History of Roundabouts

The "modern roundabout" is commonly confused with older-style traffic circles and rotaries. Traffic circles have been around almost a century, with the first documented one being built in 1905 on the southwest corner of Central Park in New York City and named after Christopher Columbus. From the start, traffic circles provided the ability for a city to tie a number of intersecting streets together and make a landscaped central circle that had aesthetic value to the community. Many large circles or rotaries were built in the United States until the 1950s when they fell out of favor. The older-style rotaries enabled high-speed merging and weaving of vehicles that led to a high crash experience.

The modern roundabout was developed in the United Kingdom to rectify problems associated with these traffic circles. In 1966, the United Kingdom adopted a mandatory "give-way" rule at all circular intersections, which required entering traffic to give way, or yield, to circulating traffic. This rule prevented circular intersections from locking up by not allowing vehicles to enter the intersection until there were sufficient gaps in circulating traffic.

What is a Modern Roundabout?

A modern roundabout is a one-way circular intersection without traffic signals in which traffic flows around a center island. Roundabouts feature yield control for all entering traffic, channelized approaches and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 30 mph. Roundabouts must be designed to meet the needs of all users—drivers, pedestrians, pedestrians with disabilities and bicyclists. When designing roundabouts, special considerations must be given to the needs of pedestrians with visual disabilities who are unable to judge adequate gaps in traffic at roundabouts. Proper site selection and pedestrian channelization are essential to making roundabouts accessible to all users. Roundabouts can also be designed for trucks and larger vehicles and in geographic areas where significant snowfall is the norm during the winter.

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Features of Modern Roundabouts

The design and traffic control features of roundabouts are as follows:

- **Yield control** is used on all entries.
- The **circulatory roadway** has no traffic control. Circulating vehicles have the right-of-way. All vehicles circulate counter-clockwise and pass to the right of the central island.
- **Central island.** Once within the circulatory roadway, vehicles' paths are further deflected by the central island.
- **Pedestrian access** is allowed only across the legs of the roundabout, behind the yield line to the circulatory roadway. Pedestrian crossings are located at least one vehicle length upstream of the yield point.
- **Splitter island.** A splitter island is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic and provide storage space for pedestrians crossing the road in two stages.
- **Yield line** is a pavement marking used to mark the point of entry from an approach into the circulatory roadway. This is generally marked along the inscribed circle. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.
- **Landscaping buffer** Landscaping buffers are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross only at the designated crossing locations. Landscaping buffers can also significantly improve the aesthetics of the intersection.
- **Accessible pedestrian crossings.** Accessible pedestrian crossings should be provided at all roundabouts. The crossing location is set back from the yield line and the splitter island is cut to allow pedestrians, wheelchairs, strollers and bicycles to pass through. Tactile surfaces should be used to warn pedestrians with visual disabilities that they are about to enter the roadway.

Roundabout Safety

Research indicates that well-designed roundabouts can be safer and more efficient than conventional intersections. Safety benefits of roundabouts include:

- Roundabouts have fewer conflict points in comparison to conventional intersections. The potential for hazardous conflicts, such as right-angle and left-turn head-on crashes is eliminated with roundabout use. Single-lane approach roundabouts produce greater safety benefits than multilane approaches because of fewer potential conflicts between road users and because pedestrian crossing distances are shorter;
- Low absolute speeds associated with roundabouts allow drivers more time to react to potential conflicts, also helping to improve the safety performance of roundabouts;
- Since most road users travel at similar speeds through roundabouts, i.e., have low relative speeds, crash severity can be reduced compared to some traditionally controlled intersections;
- Roundabouts have fewer annual injury crashes than rural two-way stop-controlled intersections, and the total number of crashes at roundabouts is relatively insensitive to minor street demand volumes; and
- Roundabouts have fewer injury accidents per year than signalized intersections, particularly in rural areas. At volumes greater than 50,000 average daily traffic (ADT), urban roundabout safety may be comparable to that of urban signalized intersections.

Table 1 shows the crash frequencies (average annual crashes per roundabout) experienced at 11 intersections in the United States that were converted to roundabouts. As the exhibit shows, both types of roundabouts showed a reduction in both injury and property-damage crashes after installation of a roundabout.

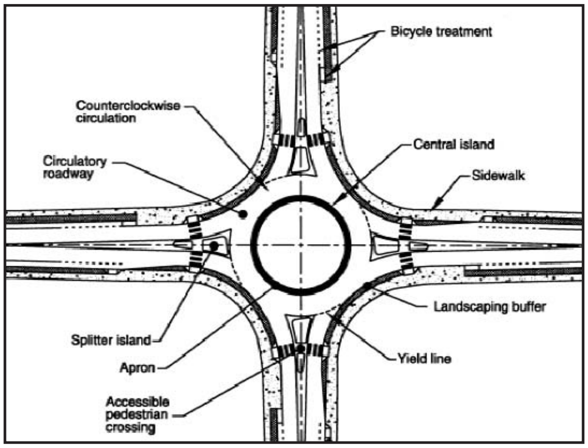
A December 2002 report by the Maryland Highway Administration indicates that 15 single-lane roundabouts have greatly improved intersection safety in the state. The analysis shows that there has been a 100 percent decrease in the fatal crash rate; a 60 percent decrease in the total crash rate; an 82 percent reduction in the injury crash rate; and a 27 percent reduction in the property damage only accident rate.

Table 1

		Before Roundabout			Roundabout			Percent Change 5		
Type of Roundabout	**Sites**	Total	Inj.[3]	PDO[4]	Total	Inj.	PDO	Total	Inj.	PDO
Small/Moderate[1]	8	4.8	2.0	2.4	2.4	0.5	1.6	-51%	73%	-32%
Large[2]	3	21.5	5.8	15.7	15.3	4.0	11.3	-29%	31%	-10%
Total	11	9.3	3.0	6.0	5.9	1.5	4.2	-37%	51%	-29%

Notes:

1. Mostly single-lane roundabouts with inscribed circle diameter of 100 ft. to 115 ft.
2. Multilane roundabouts with an inscribed circle diameter greater than 165 ft.
3. Inj. = Injury crashes
4. PDO = Property Damage Only crashes
5. Only injury crash reductions for small/moderate roundabouts were statistically significant. Source: Jacquemart, G. Synthesis of Highway Practice 264: *Modern Roundabout Practice in the United States*. National Cooperative Highway Research Program. Washington, DC: National Academy Press, 1998.



Safety Problems Susceptible to Correction by Roundabouts

The decision to install a roundabout as a safety improvement should be based on a demonstrated safety problem of the type susceptible to correction by a roundabout. A review of crash reports and the type of accidents occurring is essential.

Examples of safety problems include:

- ✦ High rates of crashes involving conflicts that would tend to be resolved by a roundabout (right-angle, head-on, left/through, U-turns, etc.);
- ✦ High-crash severity that could be reduced by the slower speeds associated with roundabouts;
- ✦ Site visibility problems that reduce the effectiveness of STOP sign control (in this case, landscaping of the roundabout needs to be carefully considered); and
- ✦ Inadequate separation of movements, especially on single-lane approaches.

Issues to Review When Considering Roundabout Design Alternatives

During the planning and alternatives development stage of a project, the following issues should be considered prior to making the decision to implement a roundabout design:

- ✦ **Context.** What are the regional policy constraints that must be addressed? Are there site-specific and community impact reasons why a roundabout of any particular size would not be a good choice?
- ✦ **Space feasibility.** Is there enough right-of-way to build the roundabout? Is right-of-way acquisition required? If "yes," this introduces administrative complications that some agencies might want to avoid.
- ✦ **Physical or geometric complications** such as right-of-way limitations, utility conflicts, drainage problems and unfavorable topography that may limit visibility or complicate construction.
- ✦ **Proximity of generators** of significant traffic that might have difficulty negotiating the roundabout, such as high volumes of oversized trucks.
- ✦ **Proximity of traffic control devices** that would require preemption, such as railroad tracks or drawbridges.
- ✦ **Traffic congestion** that would cause routine back-ups into the roundabout, such as over-capacity signals or freeway entrance ramps. The successful operation of a roundabout depends on unimpeded flow on the circulatory roadway.
- ✦ **Intersections of a major arterial and a minor arterial or local road** where an unacceptable delay to the major road could be created. Roundabouts delay and deflect all traffic entering the intersection and could introduce excessive delay or speed inconsistencies to flow on the major arterial.
- ✦ **Heavy pedestrian or bicycle movements** in conflict with high traffic volumes. (These conflicts pose a problem for all types of traffic control.)
- ✦ **Coordinated signal system.** Intersections located on arterial streets within a coordinated signal network. In these situations, the level of service on the arterial might be better with a signalized intersection incorporated into the system.

The existence of one or more of these conditions does not necessarily preclude the installation of a roundabout. Roundabouts have, in fact, been built at locations that exhibit nearly all of the conditions listed above. They may be resolved through coordination with and support from other agencies and implementation of specific mitigation actions.

Resources

1. FHWA has published a comprehensive guide called *Roundabouts: An Informational Guide*. The information supplied in this document is based on established international and U.S. practices and is supplemented by recent research. Call 202-366-5915 to order Publication No. FHWA-RD-00-067, or download this guide from the Internet at http://www.tfhrc.gov/safety/00068.htm

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Road Safety Audits: An Emerging and Effective Tool for Improved Safety

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What is a Road Safety Audit?

Every year, a large number of people are killed and injured on roads in developed and developing countries. Every year, states, counties, regions and municipalities spend considerable amount of resources on trying to reduce crashes by reconstructing and improving the roads. This work—crash reduction—is still necessary and should continue to be of high priority. However, these activities are reactive.

New roads must incorporate design and operational safety elements from the start. Roadway safety in new projects can be improved by having independent road safety specialists systematically examining and commenting on the projects, while they still only exist on paper. This is called a **road safety audit (RSA)**.

RSAs are in essence, crash prevention. The purpose is to make new roads as safe as possible—before the projects are implemented, and before any crashes happen. RSAs require an independent and systematic formal procedure for assessing or checking the crash potential and safety performance of a new road project or existing roads. Safety should be considered throughout the entire project—from planning and development, to construction and operations and maintenance.

The basis for a RSA is the application of safety principles to new project design and improvements to the highway to prevent crashes from occurring or to reduce their severity. The outcome of the audit is the identification of any potential safety issues, together with suggestions on how to address the issues. Additionally, road safety audits are systematic; auditing takes place according to agreed upon procedures, in which the parties involved have designated roles in the process.

The central principle of an RSA is the independence of the auditors. The auditors exclusively evaluate the road safety of projects—and not participants in the planning or design of the project itself. Furthermore, it is not the task of the auditors to weigh safety considerations against other considerations, e.g., economic criteria although they may be aware of them.

"We view RSAs as a proactive low-cost approach to improve safety. The RSAs helped our engineering team develop a number of solutions incorporating measures that were not originally included in the projects. The very first audit conducted saved SCDOT thousands of dollars by correcting a design problem."

Terecia Wilson,
Director of Safety
South Carolina Department of Transportation

Road safety audits can be applied to both small as well as large projects, regardless of whether the project concerns new construction or the rebuilding of existing roads.

It will often be advantageous to carry out an audit several times during the course of a project, depending on its size, complexity and character. Therefore, the following five stages have been defined:

- Stage 1: Planning
- Stage 2: Preliminary Design
- Stage 3: Detailed Design
- Stage 4: Construction
- Stage 5: Monitoring Existing Projects

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It is essential that the suggestions of the RSA are consistent with the stage of the project. For example, audit suggestions related to design details are inappropriate at the planning phase, and audit suggestions that require major design alterations are inappropriate at the detailed design phase. Experienced auditors will limit the safety audit suggestions to items that can still be practically and cost-effectively addressed at the stage of the project.

The final design-related decisions are always the responsibility of the design team and the project owner. The auditors simply provide input, and the design team and owner have absolute flexibility to accept or reject any of the audit suggestions, with proper justification and documentation.

Who needs RSA guidelines?

RSAs should be an integral part of highway planning, design, construction and maintenance. Therefore, there needs to be an explicit commitment to safety amongst elected officials, management in any transportation organization, together with an awareness of the role and benefits of safety audits.

The RSA process requires an objective approach to the assessment of crash risk. The principal method of ensuring this objectivity is through the **independent** safety assessment of projects by persons not connected with the original design. Designers and planners need to be familiar with procedures and practices, and provide the necessary background information required for the audit to be undertaken. A designated audit team should undertake the audit with experience conducting road safety engineering techniques.

What Should be Audited?

Projects eligible for audit cover a wide range of types and sizes, on different classes of roads, in urban and rural areas. The variety of design is broadly covered under the following categories:

Before RSA

After RSA

(I) major highway projects; (II) minor improvements (rehabilitation, retrofitting, upgrading) projects; (III) traffic management plans; (IV) development projects; and (V) maintenance.

Ideally, all projects should be subject to an independent safety audit. If this is not achievable within available resources, a clear procedure is required for prioritizing projects in terms of type of project and level of audit required. Projects that benefit from audits typically have the following characteristics:

- Complex, unusual, or new design characteristics;
- Significant budget or land constraints;
- A high public profile; and
- A history of high crash risk at the project location.

What resources are needed?

RSAs require the assembly of a RSA team, and some resources from the design team and the owner to compile information, attend meetings and respond to the audit suggestions.

The cost of a road safety audit is often an insignificant amount compared to the overall project cost. In the United States and Canada, highly complex RSAs for major projects (with a capital cost in the hundreds of millions of dollars) have been conducted at a cost of $30,000 to $40,000. Small audits for relatively minor projects can be completed for a cost of $15,000 or less. Audits can be conducted by in-house transportation department staff or from a consulting organization.

The cost of implementing the acceptable suggestions from the RSA (including re-design) may be relatively low and manageable, since by definition RSA suggestions need to be compatible and cost-efficient relative to the phase of the project. Allowance should be made in the original design costing and time schedule of projects for both audit and possible redesign.

What are the Benefits of RSAs?

It is difficult to quantify the benefits of road safety audits, since by definition audits are preventing crashes from occurring. Studies that have attempted to quantify the benefits of audits have yielded impressive results. In the United Kingdom, a local authority has estimated the benefit-cost ratio of an RSA to be 15:1, while TRANSIT New Zealand has estimated the benefit to cost ratio as 20:1. Cost-benefit analysis of safety audited projects in Denmark yielded an expected average first year rate of return of 146 percent.

With the low cost of conducting road safety audits, it is fair to say that audits need only to prevent a very low number of crashes, injuries and fatalities over the life of the project to provide a high benefit to cost ratio.

Who is Now Using or Planning to Use Road Safety Audits?

The RSA concept was originally developed and introduced in the United Kingdom (UK) in 1989. The benefits of such systematic checking were soon recognized by many safety professionals around the world and the following countries, among many others, are actively conducting RSAs: USA, Canada, UK, Australia, New Zealand, Denmark, Norway, Ireland, Singapore, India, Italy and Malaysia.

Road Safety Audits in the United States and Canada

There are many successful on-going RSA programs in the United States and Canada. The states of Pennsylvania, Iowa, New York, Minnesota and South Carolina are actively conducting RSAs. The first RSA for a mega-project was conducted in 2003 at the Marquette Interchange in Milwaukee, Wisconsin. In Canada, the provinces of British Columbia, Alberta and New Brunswick have been actively implementing RSAs. In 2001, a National *Road Safety Audit Guide* was published by the Transportation Association of Canada (TAC). RSA training is available in both countries, through the National Highway Institute (NHI) in the United States and through TAC in Canada.

Road Safety Audit Training

National Highway Institute (NHI)
Course 380069A
Road Safety Audit and Road Safety Audit Reviews
http://www.nhi.fhwa.dot.gov
703-235-0528

Transportation Association of Canada (TAC}
http://www.tac-atc.ca/english/educationandtraining/courses-safetyaudit.cfm
613-736-1350 ext. 261

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Work Zone Intersection Safety

It is a challenge to maintain safety and mobility at intersections in a work zone. For drivers unfamiliar with an intersection, a work zone can be a sudden, potentially dangerous surprise. For motorists who regularly drive through an intersection, a work zone can be a frustrating nuisance because of the way it adds to travel time. But the development and application of well-designed temporary traffic control plans can ensure safe mobility for workers and all road users (motorist, bicyclists and pedestrians including persons with disabilities) in an intersection work zone.

Overview

Work zones at intersections present various engineering design challenges. Intersection crashes represent about 16 percent of the total work zone fatalities in the last 5 years. The task of maintaining mobility and ensuring safety for pedestrians, bicyclists, workers, motorists and transit operations is more demanding at intersections than on road segments. The realignment of travel lanes and reduction of road capacity are often necessary to accomplish reconstruction or rehabilitation, such as pavement replacement, pavement patching, widening a street, utility work and reapplying pavement markings. All of these can cause delays and pose a threat to safety.

Transportation agency coordination with transit, police, fire, emergency medical services, utilities, schools and railroads should occur (especially in urban areas) to alert these organizations to changes in road conditions. Suggesting alternate routes is time well spent to ensure safety and travel time reliability, particularly for school buses and emergency providers.

MUTCD, Part 6, Temporary Traffic Control

The *Manual on Uniform Traffic Control Devices* (MUTCD) contains the basic principles of design and use of traffic control devices for all streets and highways open to public travel, regardless of type or class, or the public agency having jurisdiction. The latest version of the MUTCD, Part 6 titled "Temporary Traffic Control" was published November 20, 2003 and contains the standards, guidance, options and support information related to work zones. Part 6 has been significantly revised and expanded with new signs and revised "Typical Applications" detailed for a variety of street and highway work situations commonly encountered by road users. There is new language about the height and projection of signs in accordance with the American with Disabilities Act. There is also guidance for providing detectable paths for protecting pedestrians with visual disabilities in urban areas. The MUTCD can be accessed at the following Web site: http://mutcd.fhwa.dot.gov.

Cones or drums knocked out of alignment by an errant driver or a work vehicle, for example, could result in vehicles being channeled into oncoming traffic. The condition of devices should also be checked regularly to ensure that they continue to perform as intended. Modifications may also be necessary based on changing road conditions or work staging and progress. Safety in a temporary traffic control zone is the responsibility of the contractor, transportation agency and the driver. No traffic control device, however, can overcome the shortcomings of imprudent drivers.

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Work Zone Intersection Safety Goals

Motorists entering and traveling through work zones must be provided with adequate time and distance to make decisions and stop when required. Drivers should never be forced to make unexpected stops or perform unanticipated steering or crash-evasion maneuvers when approaching or within a work zone.

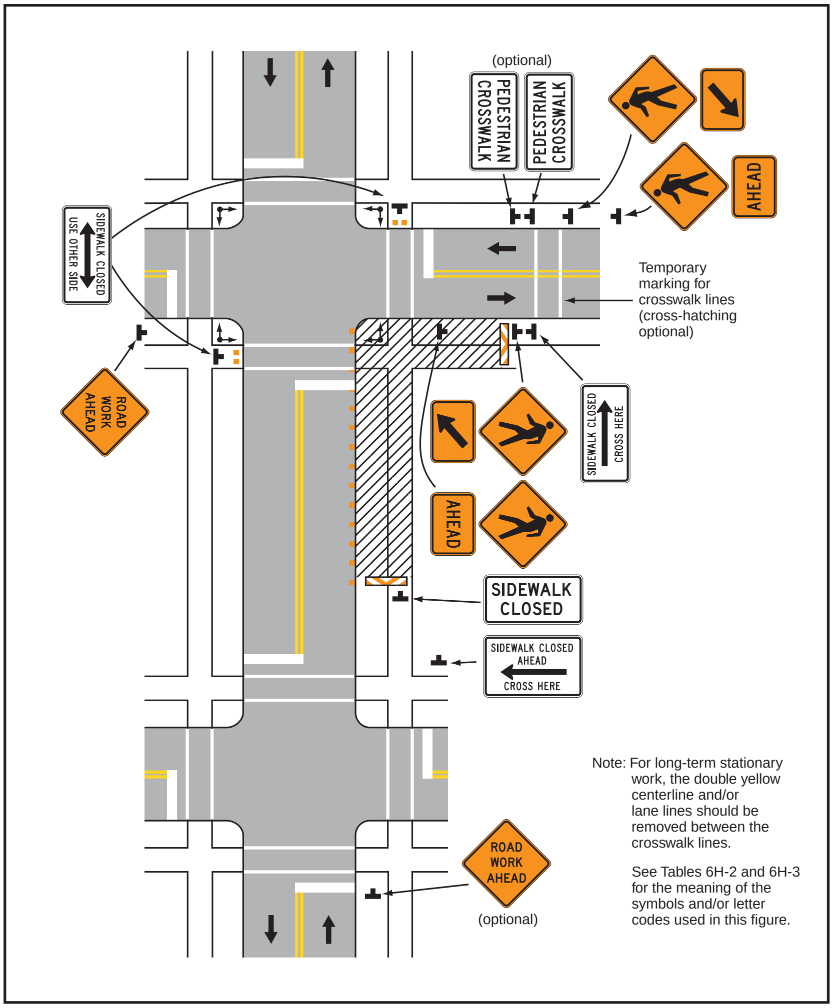
Traffic congestion in intersections should be mitigated to the greatest extent possible. If long queues are expected or are occurring because of a work zone, additional advance traffic control devices may be necessary to provide users with information about lane choice or alternate routes before being trapped in a queue. Long delays often create impatient drivers who may change their usually good driving habits and take unnecessary risks that result in potential hazards to themselves and others. Pedestrians and bicyclists may ignore signs and walk against traffic signals if they are forced to wait too long to be accommodated in a work zone. This increases their vulnerability to vehicles whose drivers may also be frustrated.

Improving Work Zone Intersection Safety

Ensuring a high level of intersection work zone safety depends on proper pedestrian accommodation, worker safety and visibility and proper traffic control.

Pedestrian Accommodations In Work Zones

- Access to temporary transit stops should be provided;
- Temporary crosswalk facilities shall be detectable;
- Curb parking shall be prohibited within 15 m (50 ft.) of the mid-block crosswalk;
- Pedestrian signals should be deactivated for closed crosswalks;



- Nighttime lighting may be considered; and
- Alternate route information should be communicated to pedestrians with visual disabilities by providing such things as audible devices, accessible pedestrian signals, or barriers and channelizing devices that are detectable.

Did you consider:

- ❑ Special consideration for seniors and pedestrians with disabilities (lower walking speeds at signalized intersections, refuge island at wide intersections, flared curbs, oversized signs and signals, night lighting)?
- ❑ Adequate pedestrian protection – physical separation from the workspace and vehicular traffic, overhead protection, etc.?
- ❑ Requirements of the American with Disabilities Act (ADA) of 1990?
- ❑ Location/access to business and residences?
- ❑ Adequate and safe detour or diversion due to sidewalk closure or blockage?
- ❑ Impact on existing pedestrian flow?
- ❑ Impact on pedestrian generators (schools, senior centers and transit stops)?
- ❑ Pedestrian information needs—advance, transition, work area and exit information?

Worker Safety at Intersections

Worker safety in work zones, especially at intersections, is an overarching consideration for highway agencies and utility companies. The combination of heavier traffic and a greater reliance on night work results in increased risks for highway workers. As a rule of thumb, flaggers or highway workers should not control intersections controlled by traffic signals or STOP signs. Police officers generally receive training for this job. Other methods that can be used to minimize and control risks for workers are as follows:

- ❑ **High-visibility apparel**
  All workers exposed to traffic should wear high-visibility safety apparel labeled as ANSI 107-1999 and be classified as either Class 1, 2, or 3 for risk exposure;
- ❑ **Worker Training**
  All workers should be trained on how to work next to motor vehicle traffic in a way that minimizes their vulnerability;
- ❑ **Positive Separation**
  Temporary traffic barriers should be placed along the work space on various factors such as distance between workers and traffic, traffic speed and volume, time of day and duration and type of operation;
- ❑ **Worker Safety Planning**
  Planning, implementation and oversight of worker safety should be the responsibility of a competent safety specialist, and should adequately address the requirements of OSHA and the MUTCD;
- ❑ **Activity Area Planning**
  Planning the internal work activity area to minimize backing-up maneuvers of construction vehicles should be considered to minimize exposure to risk; and
- ❑ **Speed Control**
  Compliance with posted speed limits, mainly through regulatory speed zoning, funneling, lane reduction, or the use of uniformed law enforcement officers or flaggers, should be considered.

Improving Temporary Traffic Control at Intersections

When the normal function of the intersection is suspended due to roadwork, temporary traffic control planning provides for the continuity of movement of motor vehicle; bicycles; pedestrian traffic (including accessible passage); transit operations; and access (and accessibility) to utilities. Nighttime roadwork also continues to increase and the safety issues relating to traffic control are a major concern.

The following strategies can improve traffic safety and mobility in work zones:

- ❑ **Enhanced Traffic Control Devices**
  Where possible use drums, vertical panels, or Type II barricades in tapers instead of cones. These devices provide more target area than cones;
- ❑ **Visibility of Work Vehicles**
  High visibility of work vehicles at intersections, especially at night may reduce the risk of crashes;
- ❑ **Controlling Speed and Increasing Driver Awareness**
  Although designing work zones to maintain normal speeds is desirable, restrictions may be necessitated by such things as lane width reductions, severe alignment changes, or workers exposed to high-speed traffic;
- ❑ **Providing Good, Glare-Free Illumination**
  For night work at intersections properly aimed and adjusted work lights can provide good illumination without causing glare problems; and
- ❑ **Regularly check the work site to ensure that the placement and operation of traffic control devices continue to conform to applicable plans.**

Resources

The FHWA developed the *Best Practices Guidebook for Work Zone Safety* to give state and local transportation agencies, construction contractors, transportation planners, trainers and others with interest in work zone operations, access to contacts and information about current best practices for achieving work zone mobility and safety. More information on this guidebook can be obtained on the following Web site: http://ops.fhwa.dot.gov/wz/wzguidbk/.

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For more information contact:

FHWA Office of Safety
Contact: Hari Kalla
Phone: 202-366-5915
http://safety.fhwa.dot.gov/programs/intersections.htm

Institute of Transportation Engineers
Contact: Edward Stollof
Phone: 202-289-0222 x132
http://www.ite.org